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FINAL REPORT
INFORMATION TRANSFER SATELLITE CONCEPT STUDY

VOLUME IV ✦ COMPUTER MANUAL

GENERAL DYNAMICS
Convair Aerospace Division

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VOLUME IV ✦ COMPUTER MANUAL

15 May 1971

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AMES RESEARCH CENTER
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FOREWORD

This report was prepared by the Convair Aerospace Division of General Dynamics under Contract No. NAS 2-5571 for the office of Advance Research and Technology (OART) of the National Aeronautics and Space Administration. The work was administered under the Technical direction of the Advanced Missions and Concepts Division of OART located at Ames Research Center.

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1

INTRODUCTION

The Satellite Telecommunications Analysis and Modeling Program (STAMP), developed by Convair, under contract to NASA/Ames provides the user with a flexible and comprehensive tool for the analysis of ITS system requirements. While obtaining minimum cost design points, the program enables the user to perform studies over a wide range of user requirements and parametric demands. The program utilizes a total system approach wherein the ground uplink and downlink, the spacecraft, and the launch vehicle are simultaneously synthesized. A steepest descent algorithm is employed to determine the minimum total system cost design subject to the fixed user requirements and imposed constraints. In the process of converging to the solution, the pertinent subsystem tradeoffs are resolved.

STAMP provides the system designer with the capability to consider a wide variety of communication systems. By appropriate specification of the pertinent input variables, the program can be made to cycle through the various types of subsystem elements and user requirements to be considered. Minimum cost solutions obtained can be compared to determine desired configurations.

STAMP can handle data in any one or combination of four different data types: audio, video, facsimile, and digital data. The program design is such that computations are performed on a per beam basis eliminating the need for assuming a nominal area of coverage and uniform ground system for the case of multiple beams. Each beam may individually handle any of the four previously mentioned data types. The logic also includes a variety of receive and transmit capability options for the ground stations.

The program can be used as a tool in performing required sensitivity analyses. For example, it can be employed to determine the effected change in the total system cost resulting from a perturbation of any of the design parameters, the sizing constraints, and/or the subsystem parameter relationships, as well as the key user requirements such as S/N, frequency, and area of coverage.

This report documents STAMP. Section 2 provides a technical analysis and a description of the principal techniques employed in the program.

2

TECHNICAL DISCUSSION

2.1 PROGRAM DESCRIPTION

The ITS synthesis program is essentially structured into five major portions: the driver program, the spacecraft system submodels, the uplink and downlink ground system models, the steepest descent iterative process, and other required models such as the signal propagation and sizing models (see Figure 2-1).

In its present form it can handle a list of up to 78 constrained parameters including spacecraft weight, spacecraft volume, spacecraft prime power supply, and transmitter power out/channel at the spacecraft and at the ground uplink facilities. The independent design parameters are chosen from the set of ground antenna gains (diameters) and receiver noise temperatures (noise figures).

The synthesis program is completely modularized in the sense that the various models have been written as separate subroutines and may be modified or interchanged with a minimum amount of effort. The program essentially consists of 35 fixed purpose subroutines representing the various models required to synthesize a communications system. Figure 2-2 illustrates the subroutine breakdown and their main functions. Briefly, the ITS Driver program controls overall execution and essentially performs all of the needed initialization. Subroutine EQUAT maintains control over the computation of the dependent parameter values. This subroutine controls computation of the required transmitter powers and the costs, weight, and volume terms for the various subsystems in addition to sizing the power subsystem in the spacecraft. It computes the cost of the selected launch vehicle and computes total system cost. Subroutine SPCRFT contains the actual logic for the sizing and costing of the various spacecraft submodels. As illustrated, each of the various submodels is represented as a separate subroutine. Also included is a user's diagnostic routine (DIAGN) to provide specific diagnostic messages during execution. These do not include the required general purpose subroutines which are listed in Appendix B.

The general logic flow of the program operation is given in Figure 2-3. Beginning with an initial design point and fixed user requirements, the program first computes

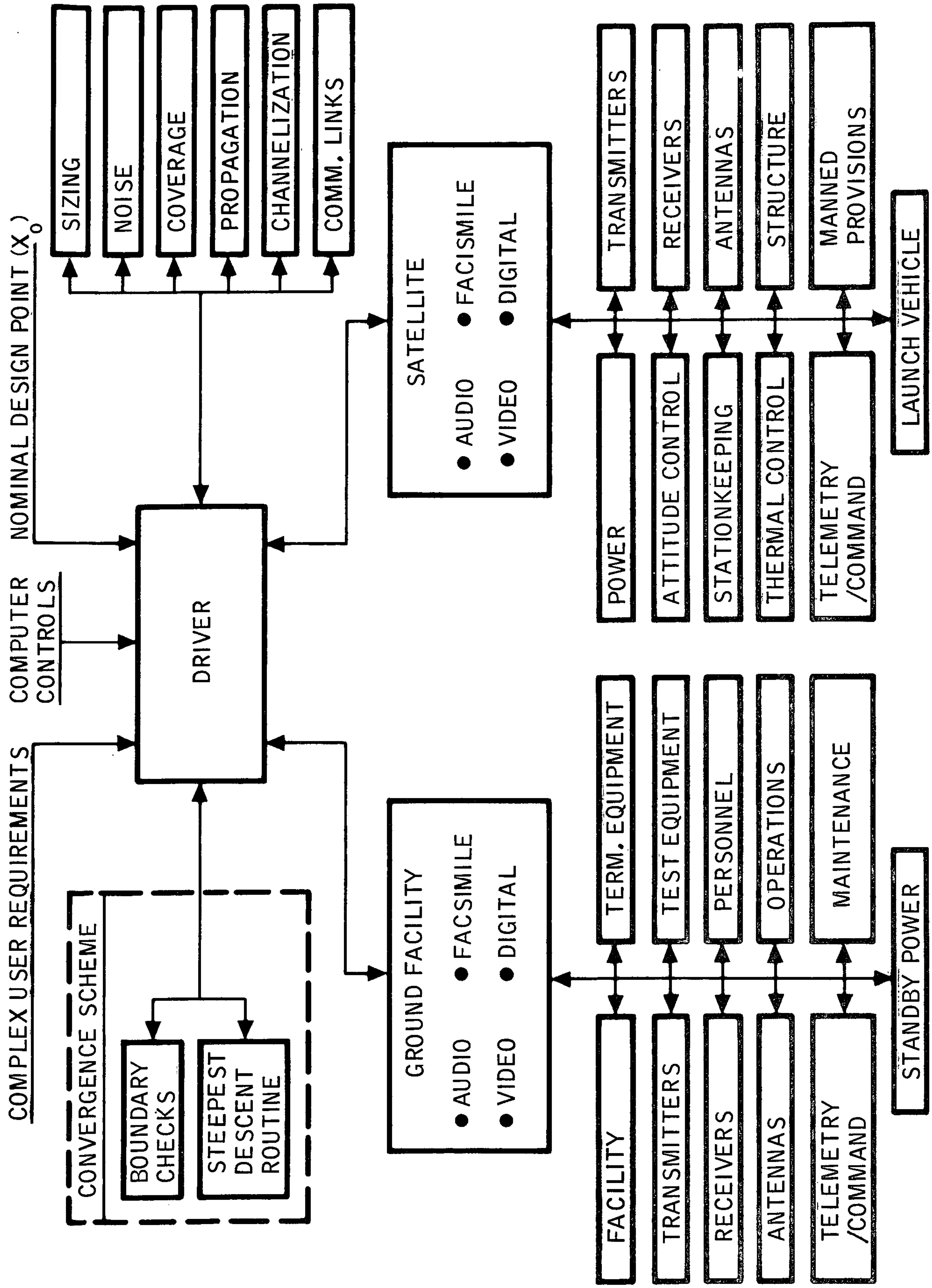


Figure 2-1. Synthesis program block diagram.

ITS DRIVER PROGRAM — CONTROLS OVERALL EXECUTION

INPTX	CONTROLS INPUT
AOC	ORBIT/COVERAGE MODEL
DIAM	COMPUTES SPCRFT ANT SIZE
PARBDS	SIZING MODEL
ATTEN	SIG. PROP/NOISE MODEL
XBD	CHECKS $\overline{X}_0$ AGAINST BDS
EQUAT	COMPUTES $\overline{Y}(\overline{X})$
BNDV	CHECKS $\overline{Y}$ FOR BD VIOLATION
OPTMUM (MAXBD)	MIN. COST CONVERGENCE ROUTINE
CHANEL	COMPUTES CHANNEL REQUIREMENT
CNVRGE	CONVERGENCE TEST
OUTPT1, OUTPT2	CONTROLS OUTPUT

EQUAT— COMPUTES $\overline{Y}$

GRDFAC	UPLINK/DOWNLINK MODEL FOR CLASS I/II
GDIRCT	DIRECT RCVR GRD DWNLNK MODEL
DGDEP	ITER SCHEME ON GRD ANT GAIN AND DIAM
DISCR	COMPUTES GRD ANTENNA DISCRIMINATION
PXTR	COMPUTES REQ'D XMTR POWER/CHANNEL
SPCRFT	SPCRFT MODEL
LNCHV	LAUNCH VEHICLE
TCOST	TOTAL SYSTEM COST

SPCRFT (SPACECRAFT SUBMODELS)

ANTS	ANTENNA	STNKP	ST. KEEPING
ATTCN	ATTITUDE CONTROL	STRUC	STRUCTURE
MANPRV	MANNED PROVISIONS	THRML	THERMAL CONTROL
MTPLXS	MULTIPLEXER	TLMCMD	TELEMETRY & COMMAND
POWER	POWER	XMTR	
RCVRS	RECEIVERS	(PLACE)	SPCRFT TRANSMITTER

MISCELLANEOUS		FUNCTIONS	
DIAGN	DIAGNOSTIC ROUTINE	EXPL	
		QUAD	PARAMETRIC EQ'S.
		PFUNC	

Figure 2-2. ITS synthesis program subroutine structure.

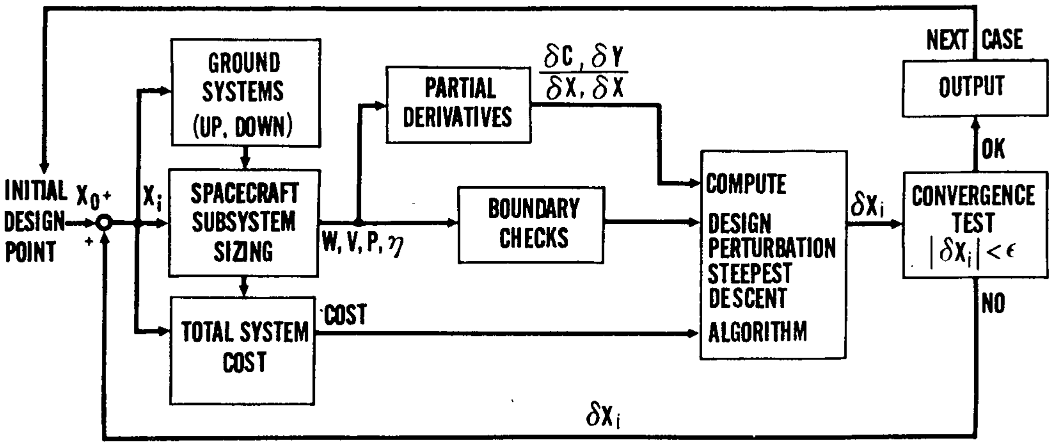


Figure 2-3. Program operation flow diagram.

the required spacecraft antenna size based on the desired frequency and area of coverage. It proceeds to cost the ground systems and to compute the required power out/channel via the link equations. The satellite system is sized and its cost computed. Following this the total system cost is determined. Parameters are checked for boundary violations and the required partial derivatives are found. The optimum design parameter perturbation is computed, and, if convergence has not yet been achieved, the process is repeated with the newly perturbed design point until convergence is achieved. If more cases are to be considered, the program repeats the entire process. The program was designed, tested, and debugged using the CDC 6400 computing facility at Convair Aerospace and eventually modified for use on NASA/Ames IBM 360 system. The IBM version may incorporate the overlay feature to conserve required core space. This overlay is described in Appendix C. Average core requirement on the CDC system is 76000_8^* words including the routines required by the operating system. The IBM 360 version with overlay and use of double precision requires approximately 160 kilobytes of storage. The double precision is necessary because of the shortened word length on the IBM machine, 32 bits/word as opposed to 60 bits/word, and the sensitivity of parts of the system to small perturbations.

*$76000_8 = 31744_{10}$

2.2 MATHEMATICAL DESIGN OPTIMIZATION TECHNIQUE

The Convair Aerospace ITS system design optimization program uses a steepest descent iterative process, which is a modified gradient technique,to determine the minimum cost design point for a given system configuration. At each iteration the nominal design point is perturbed in such a way as to cause the maximum rate of decrease in total system cost to be consistent with the design constraints.

The philosophy of the technique is that the direction of steepest descent is given as the direction of the negative cost gradient. When a physical constraint (e.g., satellite weight) is encountered, the new direction is given by the component of the negative cost gradient tangent to the constraint surface. Referring to Figure 2-4, the lowest point D in the valley represents the minimum cost design point; the cost contours represent the increase in cost as the system design deviates from the optimum. The constraint boundary represents a "fence" or physical constraint which prohibits attainment of the specified goal. The process begins at Point A and proceeds iteratively from one contour to the next to Point B, the first encounter with the constraint. It then proceeds along the boundary (in the direction of steepest descent) until it finds the lowest Point C. This represents the lowest achievable point consistent with the imposed constraint.

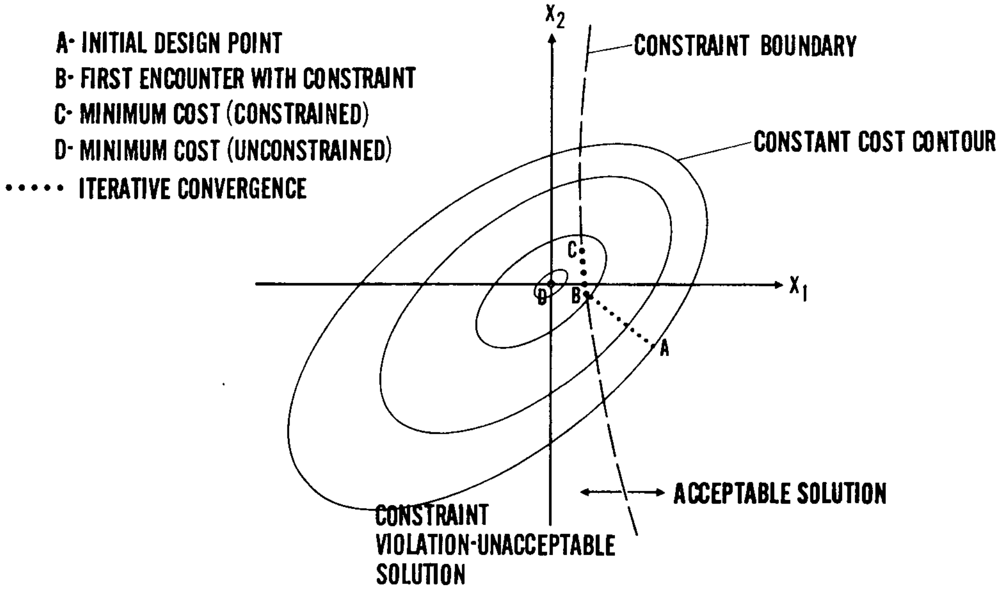


Figure 2-4. Steepest-descent iterative process.

If Δy_j is the amount by which the j^{th} boundary is violated and g represents the gradient of total system cost, then the perturbation in $\overline{X}$, the vector of independent design parameters, is given by

$$\overline{\Delta X} = - K_c \left[I - \Phi (\Phi^T \Phi)^{-1} \Phi^T \right] g - K_y \Phi (\Phi^T \Phi)^{-1} \Delta y_j$$

where Φ is the gradient of the constraint relationship. The derivation of this equation is given in Appendix A.

If K_y is set equal to unity, the second term represents, to first order terms, the amount by which $\overline{X}$ must be changed to reduce Δy_j to zero. If K_y is less than one, the boundary violation is partially reduced. The first term represents the component of the cost gradient parallel to the constraint boundary and is orthogonal to the second term. For small ΔX_i (so that the linear approximation is valid), the first term reduces the cost and contributes nothing directly to the boundary violation. If no boundaries are violated, then Δy_j and Φ are zero, so that the equation reduces to

$$\Delta X = - K_c \, g$$

which represents a perturbation in the direction of the negative of the cost gradient.

Since K_c is arbitrary,some control over the step-size must be introduced. The principle used in determining the magnitude of the step is that if successive steps have been in the same direction it is desirable to increase the step-size in order to speed up the convergence process. On the other hand, if successive steps have been in opposite directions, it is desirable to decrease the step-size since the optimum design point has been overshot. Furthermore, it appears that larger step-sizes are most desirable in the early iterations to hasten arrival to the vicinity of the optimum design point. Once in the vicinity of the optimum, smaller steps would prove more practical. To afford faster convergence, the step size S is replaced with a vector of dimension N. This enables the optimization scheme to scale each component relative to its ability to converge. The modification of the scale factor is based on the following criteria. Let $\overline{\Delta X}_1$ and $\overline{\Delta X}_2$ be the two previous perturbations and $\overline{\Delta X}$ be the present.

Furthermore, let $C_1 = \overline{\Delta X}_1 \cdot \overline{\Delta X}$ and $C_2 = \overline{\Delta X}_2 \cdot \overline{\Delta X}$ where the indicated products are vector dot products. Then

SCALE = .5 × SCALE if $C_1 < 0$,
SCALE = 2 × SCALE if $C_1, C_2 > 0$,
SCALE = 32 if SCALE > 32, and
SCALE = .5 × SCALE if $i \geq 30$ and SCALE > 1 where i = iteration index.

With the step-size, S_i, thus specified, the appropriate value of K_c can be determined from

$$K_c = \sqrt{\frac{S_i^2 - K_y^2 \cdot \Delta y_i^T (\Phi^T \Phi)^{-1} \Delta y_i}{H^T H}}, \quad H = \left[I - \Phi(\Phi^T \Phi)^{-1} \Phi^T \right] g$$

in the event of a boundary violation. If the solution is unconstrained K_c is determined from

$$K_c = \frac{S_i}{|g|}$$

These are the equations used by the ITS convergence routine. It is important to keep S_i from growing to a point at which a large number of iterations would be required to bring it down. Therefore the upper bound is placed on S_i.

The rate of convergence to the minimum cost design point is dependent upon the relative sensitivities of the cost to each of the design parameters. Since the algorithm operates on the most sensitive parameters, convergence to the optimum value of the less sensitive parameters can be slow. For this reason it is often desirable to rescale the units of the design parameters to equalize these sensitivities.

An example of how the process actually converges, consider Figure 2-5 which illustrates a particular case using this technique. In this example, a volume constraint of 170 cubic feet has been imposed on the volume of the solar array. Since the initial design point violates the constraint, several iterations are required to return this quantity to the specified boundary. The process then proceeds along the boundary until the minimum cost solution is achieved. Also illustrated is the interaction of the ground downlink antenna size and the ground downlink receiver noise temperature during the convergence process. The minimum at iteration three actually represents the unconstrained minimum cost design point. The ITS synthesis program is designed to provide a brief summary output at each iteration, so that the user is made aware of such occurrences.

2.3 PARAMETRIC SUBSYSTEM MODELS

The ITS subsystem models include the pertinent elements required to obtain a complete synthesis of the total system. The cost, weight, and volume parametric relationships and fitted curves may be found in the Appendix section of Volume 3.

In general, the curves were fit with one of three types of equations. The forms of these equations is given as one of the following:

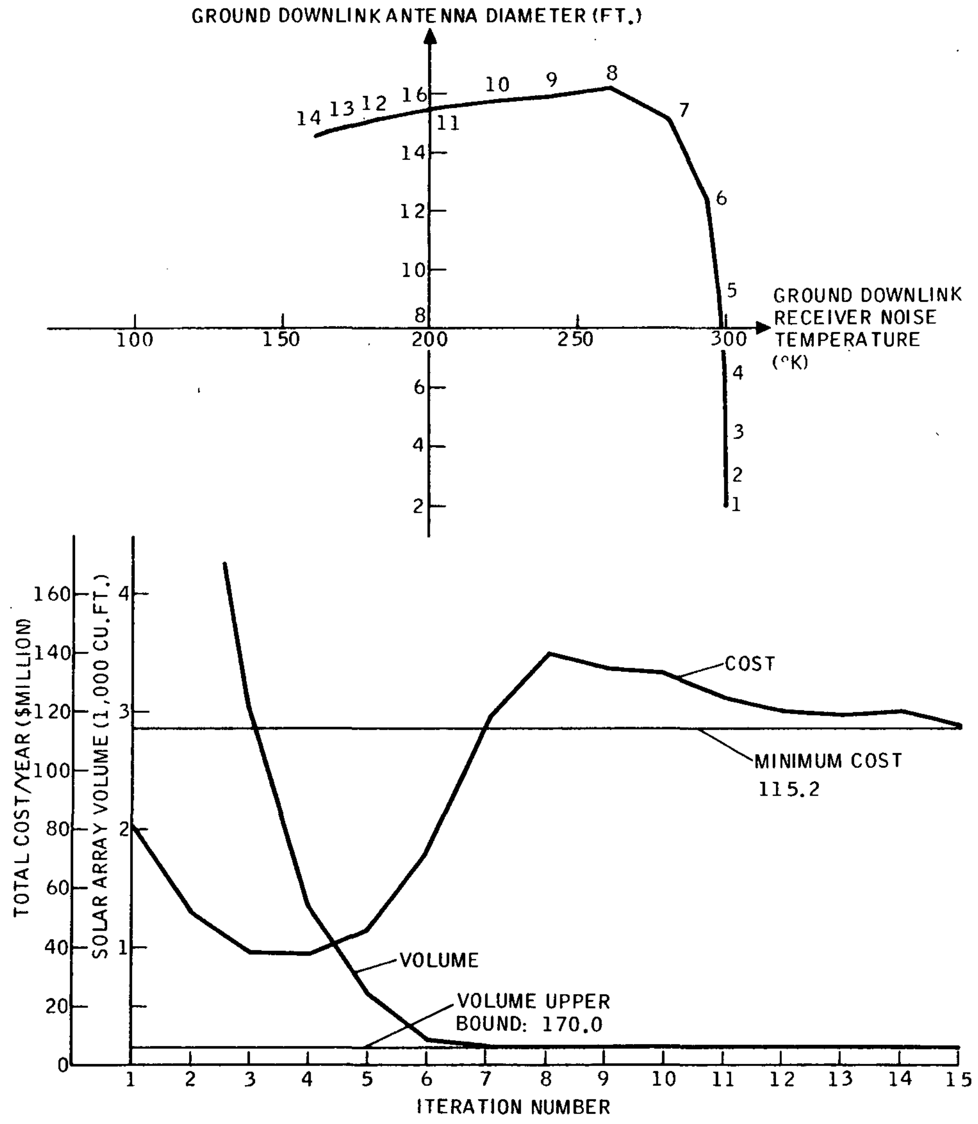


Figure 2-5. Illustration of convergence process.

(1) $y = 10^{g(z)/10}$

where $g(z) = a + bz + cz^2$, $z = 10 \log P$, and P represents the value of the parameter determining y,

(2) $y = a + bx^c$, and

(3) $y = a + bx + cx^2$.

Other relations are indicated by either linear or exponential fits or are given as thruput values.

The curves used during this study are applicable over a wide range of parametric values. Where it was impossible to obtain an accurate fit with a single equation, the curve was fit in more than one piece. The breakpoint, in most cases, is variable and is included in the input lists.

The system synthesis incorporates a loss model for both the uplink and downlink portions of the beam, a noise model, and scale factors to account for redundancy in the spacecraft. It contains an orbit and area of coverage model which computes the required beamwidths and a separate model to compute the channel characteristics. Also included is a satellite power subsystem model.

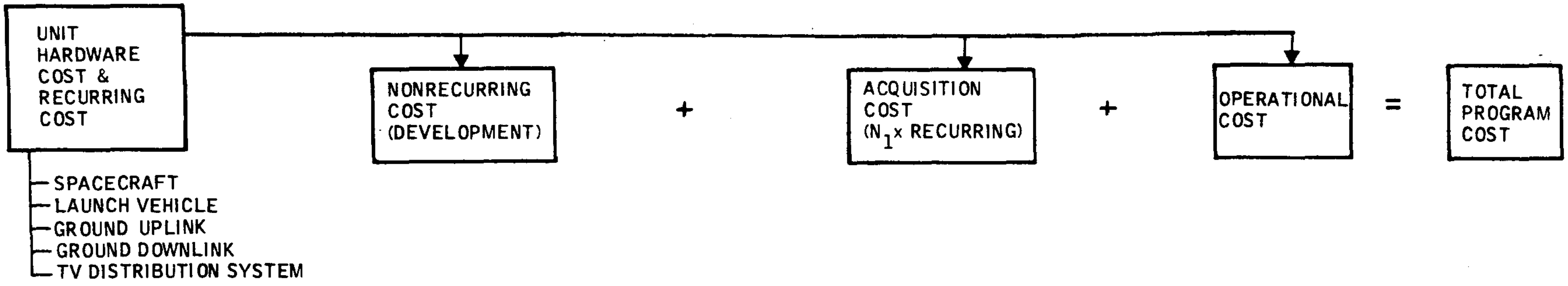
The loss and noise model is discussed in Section 2.6; the area of coverage model in Section 2.5, and the communication links in Section 2.9. A discussion of the redundancy scale factors is in Section 2.8. The cost elements are in Section 2.4. The choice of parameters for the dependent and independent design vectors is discussed in Section 2.10, while the power subsystem model is found in Section 2.7.

2.4 COST MODEL

The ITS cost model summarized in Figure 2-6 illustrates the breakdown per cost element. The model computes the acquisition, non-recurring (development), operation, and maintenance cost to form the total cost.

Table 2-1 is a tabulation of the cost model as implemented in the computer program. The associated array name as used in the program is given together with a descriptive title and whether it is computed from an input curve or is input as a thruput value. It should be noted that each of the individual cost items is dimensionedby the number of beams. The cost-estimating relationships are given in the Appendix section of Volume 3.

In referencing the table, note that the following definitions are provided:



- SATELLITE MODEL:

<u>UNIT RECURRING COST</u>

Subsystem Unit Hardware
- Structure
- Electrical Power & Batteries
- Stabilization & Control
- Reaction Control
- Environmental Control
- Life Support (manned systems only)
- TT&C/Instrumentation
- Uplink Antenna, Receiver & Repeater
- Transmitter
- Transmitting Antenna & Feed

Integration, Assembly & Checkout

<u>NONRECURRING COST</u>

Subsystem Design Development and Test
- Structure
- Electrical Power & Batteries
- Stabilization & Control
- Reaction Control
- Environmental Control
- Life Support
- TT&C/Instrumentation
- Uplink Antenna, Receiver & Repeater
- Transmitter
- Transmitting Antenna

Engineering Test Model or Prototype Hardware

System Level Design, Integration, Test & Management

NASA Center Support

GSE Design Development & Test

GSE Hardware

Facilities & STE

<u>ACQUISITION COST</u>

Unit Recurring Hardware Cost

NASA Center Support/Unit

Launch Operations/Support/Spares

<u>OPERATIONS COST</u>

Replacement Spacecraft Hardware Cost

Figure 2-6. Cost model for each element.

Table 2-1. Cost Model

I.	**GROUND UPLINK/DOWNLINK — CLASS I (CLASS II)**				
A.	**Acquisition Cost**				
1.	Facilities		ACQC1	(ACQC2)	Curve
2.	Terminal equipment	(audio)			
3.		(video)			
4.		(facsimile)			
5.		(digital data)			
6.	Transmitter	(audio)			
7.		(video)			
8.		(facsimile)			
9.		(digital data)			
10.	Antenna				
11.	Receiver				
12.	Standby power				
13.	Test equipment				Thruput
14.	Total acquisition cost — Class I (Class II)		TACQC1	(TACQC2)	ΣACQC1 (1, I) thru ACQC1 (13, I)
B.	**Operations Cost (per year)**				
1.	Terminal equipment	(audio)	OPC1	(OPC2)	N_1%×ACQC1 (2, I)
2.		(video)			N_2%×ACQC1 (3, I)
3.		(facsimile)			N_3%×ACQC1 (4, I)
4.		(digital data)			N_4%×ACQC1 (5, I)
5.	Transmitter	(audio)			Curve
6.		(video)			
7.		(facsimile)			
8.		(digital data)			Curve
9.	Receiver				N_5%×ACQC1 (10, I)
10.	Personnel				Curve
11.	Total operation cost — Class I (Class II)		TOPC1	(TOPC2)	$N_L \times \Sigma$OPC1 (1, I) thru OPC1 (10, I)

Table 2-1. Cost Model (continued)

C. Installation Cost					
1.	Terminal equipment	(audio)	CINST1	(CINST2)	$N_6\% \times ACQC1\ (2, I)$
2.		(video)			$N_7\% \times ACQC1\ (3, I)$
3.		(facsimile)			$N_8\% \times ACQC1\ (4, I)$
4.		(digital data)			$N_9\% \times ACQC1\ (5, I)$
5.	Transmitter	(audio)			$N_{10}\% \times ACQC1\ (6, I)$
6.		(video)			$N_{11}\% \times ACQC1\ (7, I)$
7.		(facsimile)			$N_{12}\% \times ACQC1\ (8, I)$
8.		(digital data)			$N_{13}\% \times ACQC1\ (9, I)$
9.	Antenna				Curve
10.	Receiver				$N_{14}\% \times ACQC1\ (11, I)$
11.	Standby power				$N_{15}\% \times ACQC1\ (12, I)$
12.	Design, integration, & Mgmt				$N_{16}\% \times \Sigma ACQC1\ (2, I)$ thru $ACQC1\ (11, I)$
13.	Total installation cost — Class I (Class II)		TINC1	(TINC2)	$\Sigma CINST1\ (1, I)$ thru $CINST1\ (12, I)$
D. Maintenance Cost (per year)					
1.	Facility		CMNT1	(CMNT2)	$M_1\% \times ACQC1\ (1, I)$
2.	Terminal equipment	(audio)			$M_2\% \times$ (2, I)
3.		(video)			
4.		(facsimile)			
5.		(digital data)			
6.	Transmitter	(audio)			
7.		(video)			
8.		(facsimile)			
9.		(digital data)			
10.	Antenna				
11.	Receiver				
12.	Standby power				$M_{12}\% \times$ (12, I)
13.	Total maintenance cost — Class I (Class II)		TMNTC1	(TMNTC2)	$N_L \times \Sigma CMNT1\ (1, I)$ thru $CMNT1\ (12, I)$

Table 2-1. Cost Model (continued)

II.	**GROUND DOWNLINK — DIRECT**		
A.	**Unit Recurring**		
1.	Antenna	UREC3(1)	Curve
2.	Receiver (Beam 1)	UREC3(2)	
3.	(Beam 2)	(3)	
4.		(4)	
5.		(5)	
6.		(6)	
7.	Receiver (Beam 6)	UREC3(7)	Curve
B.	**Acquisition Cost**		
1.	Antenna	ACQC3 (1, I)	UREC3(1)
2.	Receiver	ACQC3 (2, I)	UREC3(I+1)
3.	Total acquisition cost - direct	TACQC3	(1) + (2)
C.	**Installation Cost**		
1.	Antenna	CINST3 (1, I)	Curve
2.	Receiver	CINST3 (2, I)	50% × ACQC3(2, I)
3.	Total installation cost - direct	TACQC3	(1) + (2)
D.	**Maintenance Cost (per year)**		
1.	Antenna	CMNT3 (1, I)	10% × ACQC3(1, I)
2.	Receiver	CMNT3 (2, I)	10% × ACQC3(2, I)
3.	Total maintenance cost - direct	TMNTC3	$N_L \times [(1) + (2)]$

Table 2-1. Cost Model (continued)

III. SPACECRAFT SYSTEM

A. Acquisition Cost

1.	Prime power	ACQC4(1)	Curve
2.	Secondary power (batteries)	(2)	
3.	Power conditioning		
4.	Power distribution		
5.	Antenna		
6.	Transmitter		
7.	Multiplexer		
8.	Receiver		Curve
9.	Structure		Thruput
10.	Thermal control		Curve
11.	Stationkeeping		
12.	Attitude control		Curve
13.	Telemetry and command		Thruput
14.	Manned provisions (life support subsystem)		Thruput
15.	Integration, assembly, & checkout		7.5% × Σ(1) thru (14)
16.	Center support		15% × Σ(1) thru (15)
18.	Total spacecraft acquisition	TACQC4	$N_S \times N_L/N_{LS} \times$ Σ(1) thru (17)

B. Research and Development

1.	Prime power	RDC4(1)	Curve
2.	Secondary power (batteries)	(2)	
3.	Power conditioning		
4.	Power distribution		
5.	Antenna		
6.	Transmitter		
7.	Multiplexer		
8	Receiver		Curve
9.	Structure		Thruput
10.	Thermal control		Curve
11.	Stationkeeping		
12.	Attitude control		Curve
13.	Telemetry and command		Thruput
14.	Manned provision (life support subsystem)		Thruput

Table 2-1. Cost Model (continued)

B. Research and Development (continued)			
15.	Prototype	RDC4(15)	ΣACQC4(2) thru (14) + 15% × ACQC3(1)
16.	Design, integration, and management	RDC4(16)	50% × Σ(1) thru (14)
17.	Center support and development	RDC4(17)	5% × [Σ(1) thru (14)+(16)]
18.	Ground support equipment	RDC4(18)	50%× ΣACQC4(1) thru(14)
19.	Total spacecraft R/D	TRDC4	Σ(1) thru (18)
IV.	LAUNCH VEHICLE		
A. Acquisition Cost			
	Unit Acquisition		Thruput
	Total Acquisition		$N_S/N_{SL} \times N_L/N_{LS} \times$ ACQC5
B.. Research and Development			
	R/D Cost		Thruput
	Total R/D Cost		RDC5

N_L — total system lifetime in years

N_S — number of identical satellite systems

N_{LS} — total satellite lifetime in years

N_{SL} — number of satellites per launch

Also N_1 through N_{16} and M_1 through M_{12} are variable and are included in the input lists.

The thruput cost values indicated for the launch vehicle are calculated external to the program and include the following items:

Non-recurring:

1) Launch vehicle development,
2) Fairings and adapters, and
3) Mission integration.

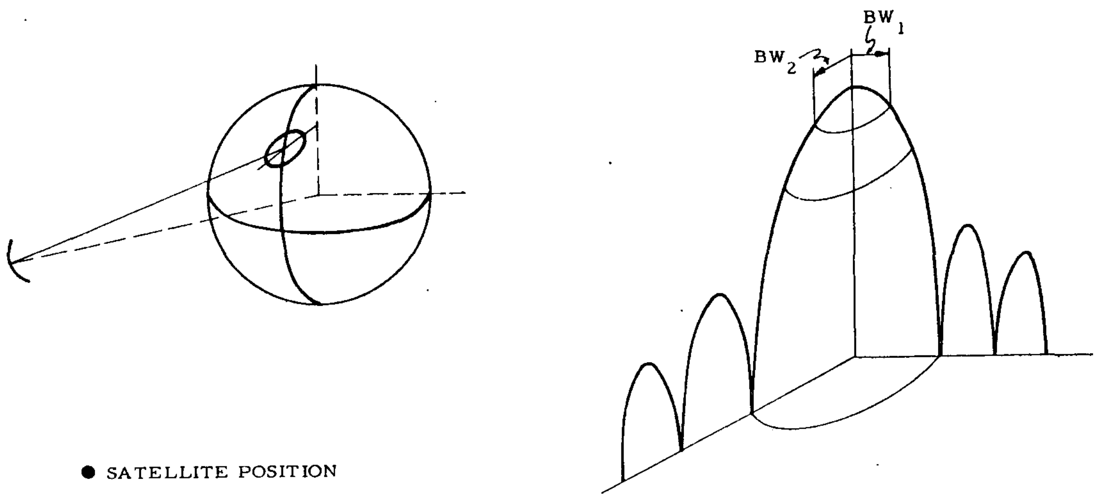
Unit-recurring:

1) Launch vehicle,
2) Fairings and adapters,
3) Launch services, and
4) Spares.

2.5 ORBIT AND COVERAGE MODEL

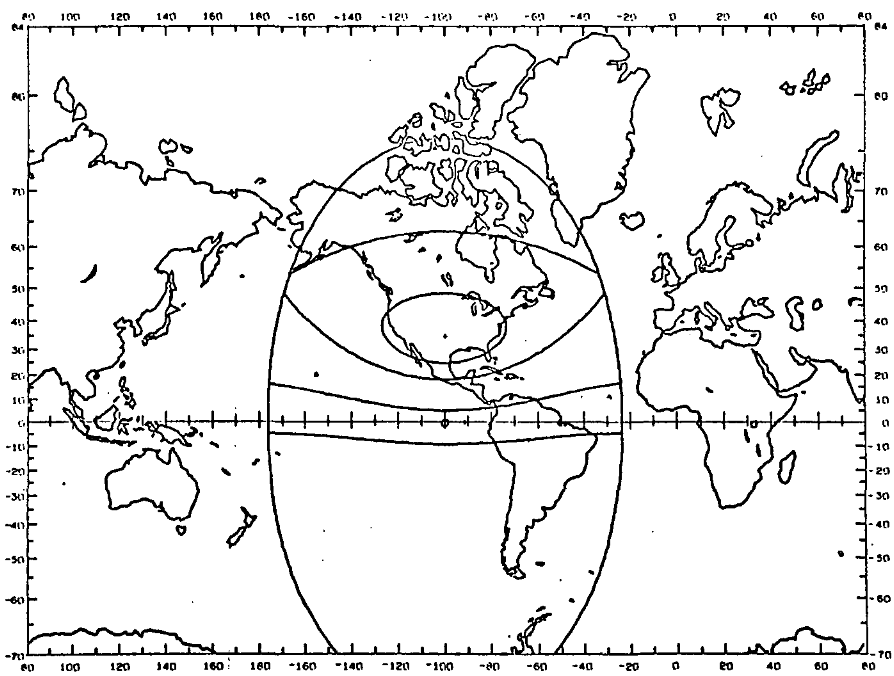
The model computes the slant range and elevation angle to the satellite and the off-axis location loss for a nominal ground station. These parameters are used in the propagation and noise models.

To yield better results, the approach during the study has been to make use of a separate model, external to the program, prior to running a particular case. This program (see Figure 2-7) accepts the position of the satellite, the coordinates of the antenna beam center, the azimuth angle of the antenna, the antenna orthogonal beamwidths, and the relative angular positions of the desired radiation levels (e.g., half-power, first sidelobe). Up to ten levels may be handled by the program. The program then computes the contours on the surface of the earth and plots on the SC-4200 plotter together with a mercator projection of the earth as in Figure 2-8. These contours are useful in determining the effectiveness of the coverage and in computing the flux density levels due to transmission. The model in the synthesis program accepts the same parameters to compute the elevation angle, major and minor axes, and location losses for each beam.



- SATELLITE POSITION
- BEAM CENTER COORDINATES
- BEAM AZIMUTH
- ANTENNA PATTERN

Figure 2-7. Orbit and coverage model.



SUB SATELLITE LONGITUDE	BEAM CENTER COORDINATES LAT LONG	BEAM AZIMUTH (+ CW)	ANTENNA BEAMWIDTHS (DEGREES)	
-100.0	35.0 -100.0	0.0	3.0 X 7.0	10/02/70

Figure 2-8. Continental United States coverage.

2.6 SIGNAL ATTENUATION/NOISE MODELS

This section presents the various attenuation and noise factors which affect the propagation between the ground uplink station, the satellite, and the ground receiving station and which are incorporated into the program. Associated curves are in the Appendix section of Volume 3.

The basic model is shown in Figure 2-9. Given the elevation angles and the slant ranges for each satellite antenna beam, the attenuation due to clouds, rain, water vapor and oxygen, and the ionosphere as well as circuit losses are determined. Additionally, the noise contributions due to these elements are calculated. Table 2-2 itemizes the terms and equations used in this model. The effective noise seen by the receiver is given by

$$T_G = T_{ANT} + T_T + T_R$$

where

$$T_{ANT} = L_{TL} \quad (T_{COS} + T_I + T_A + T_C + T_{RN}) \quad G_S$$

$$+ T_M G_M + T_E G_E$$

G_S, G_M, G_E are relative antenna gains over the three regions — sky, man-made noise, and earth.

The computation of the intermodulation noise for multicarrier operations is also made in this model. The relationship between carrier-to-intermodulation noise $(\frac{C}{M})$ and transponder backoff for various numbers of carriers is shown in Figure 2-10. For a given $\frac{C}{IM}$, or determined from the $\frac{C}{N}$, the required transponder backoff is computed as a function of the number of carriers.

2.7 POWER AND SPACECRAFT SIZING SUBMODEL

The power subsystem model is depicted in Figure 2-11. The model incorporates the various information types — audio, video, facsimile, and digital data as shown in the figure. Once the transmitter powers required to fulfill the links are determined, the power requirements are traced back to the prime power source considering the efficiency of each element in the system.

The model will allow any number of channels of each type to operate at any duty cycle, and will size the power source and batteries for operation during both the sunlit and eclipse portions of the orbit. Each transmitter and receiver will operate

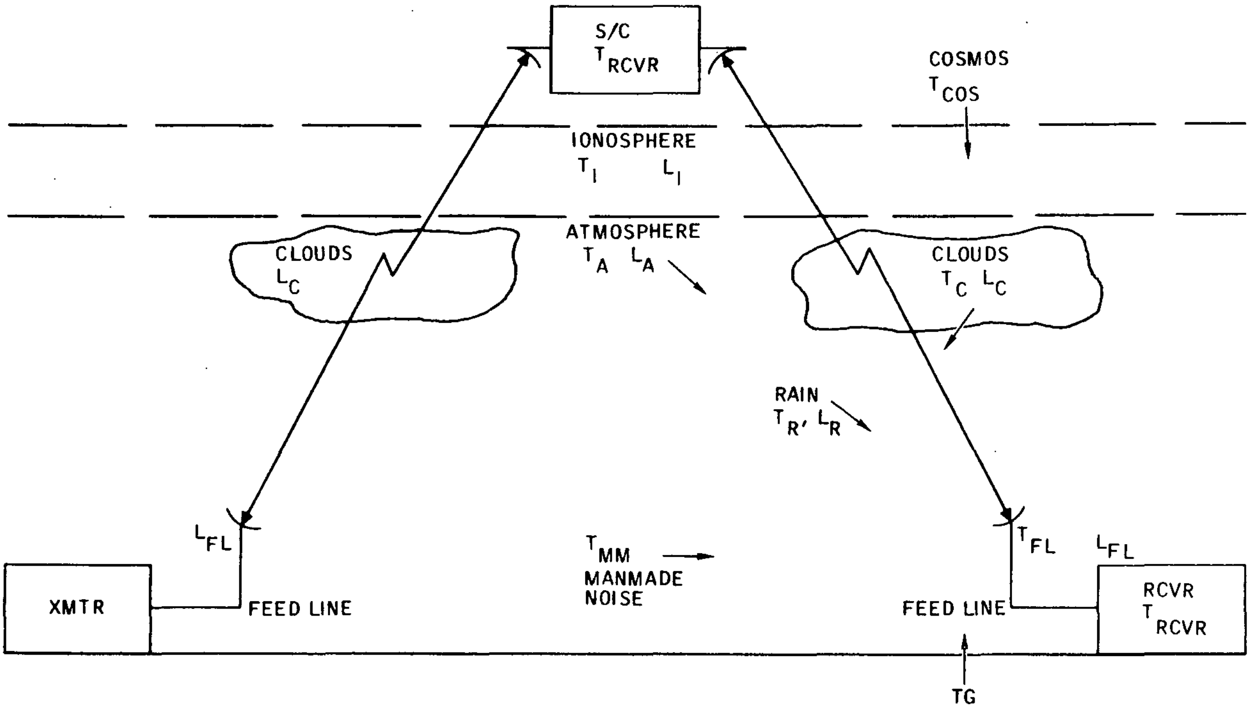


Figure 2-9. Synthesis program noise and propagation.

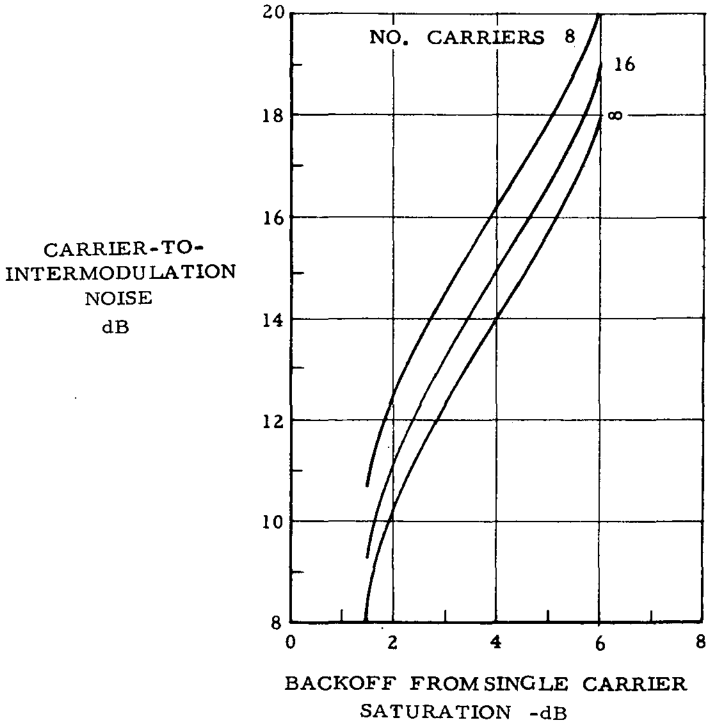


Figure 2-10. Transmitter backoff for multi-carrier operation.

Table 2-2. Terms and equations of propagation and noise model.

REGION	ATTENUATION	ABSORPTION	AMBIENT TEMPERATURE	EFFECTIVE TEMPERATURE AT RECEIVER
COSMOS	--	--	T_{COSMIC}	$T_{COS} = L_I L_A L_C L_R T_{COSMIC}$
IONOSPHERE	L_I	$1 - L_I$	T_{ION}	$T_I = L_A L_C L_R (1 - L_I) T_{ION}$
ATMOSPHERE	L_A	$1 - L_A$	T_{ATM}	$T_A = L_C L_R (1 - L_A) T_{ATM}$
CLOUDS	L_C	$1 - L_C$	T_{CLOUD}	$T_C = L_R (1 - L_C) T_{CLOUD}$
RAIN-TO SATELLITE	L_R	$1 - L_R$	T_{RAIN}	$T_{RN} = (1 - L_R)\, T_{RAIN}$
HORIZONTAL PATH	L_{RH}	$1 - L_{RH}$	T_{RAIN}	
ENVIRONMENTAL	--	--	T_{MAN}	$T_M = L_{RN}\, T_{MAN}$
EARTH	--	--	T_{EARTH}	$T_E = T_{EARTH}$
TRANSMISSION LINE	L_{TL}	$1 - L_{TL}$	T_{TL}	$T_T = (1 - L_{TL})\, T_{TL}$
RECEIVER	--	--	T_{RCVR}	$T_R = T_{RCVR}$

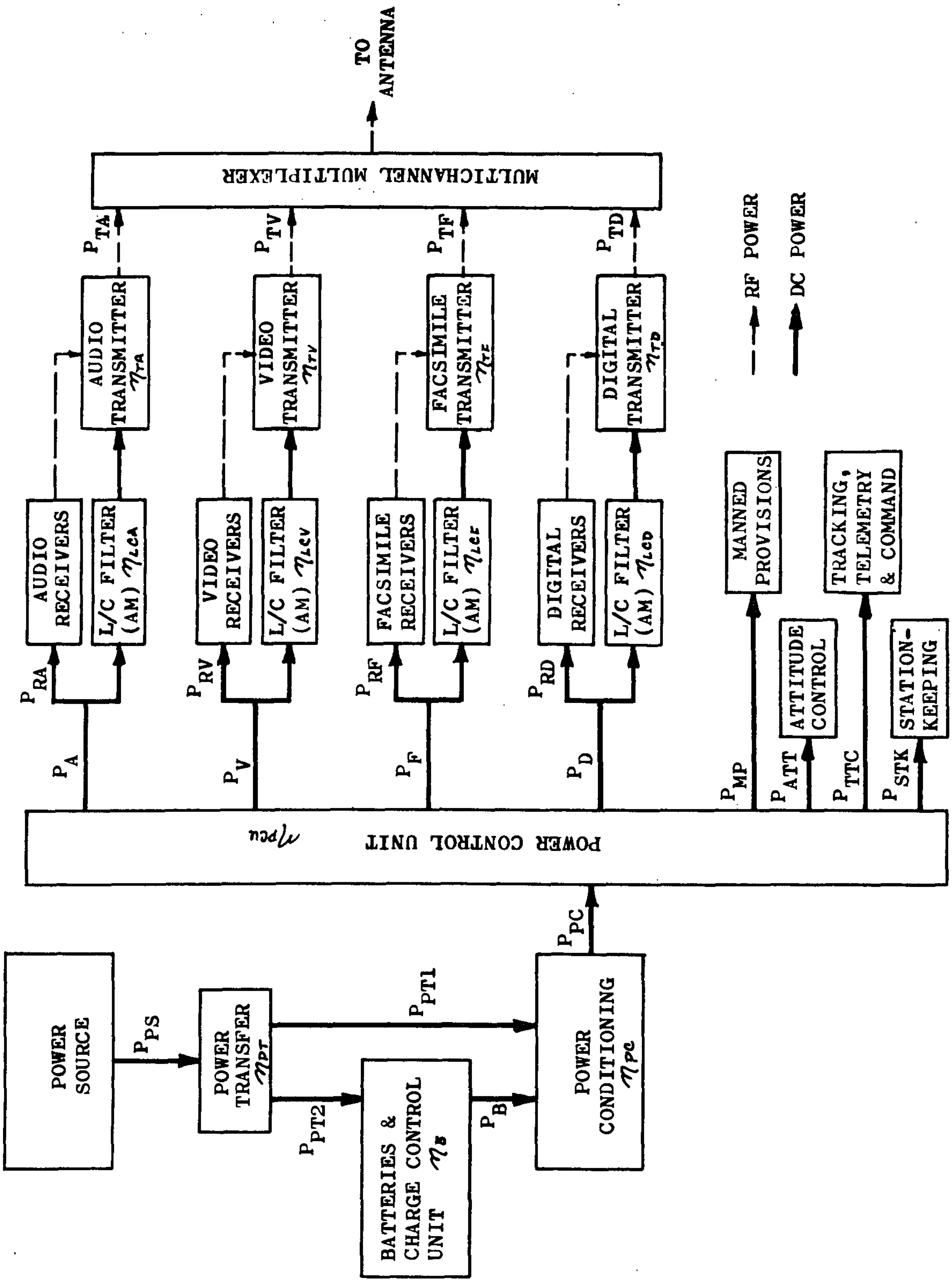


Figure 2-11. Power subsystem model.

at its full rate power or in a standby condition (nominally 10 percent full power) according to its duty cycle.

The maximum power input to each transmitter and receiver block is

$$P_a = \sum^{N_a} \left(\frac{P_{ta}}{\eta_{ta}\,\eta_{lca}} + P_{ra} \right)$$

$$P_v = \sum^{N_v} \left(\frac{P_{tv}}{\eta_{tv}\,\eta_{lcv}} + P_{rv} \right)$$

$$P_f = \sum^{N_f} \left(\frac{P_{tf}}{\eta_{tf}\,\eta_{lcf}} + P_{rf} \right)$$

$$P_d = \sum^{N_d} \left(\frac{P_{td}}{\eta_{td}\,\eta_{lcd}} + P_{rd} \right)$$

then for maximum rating

$$P_{pcu} = P_l + P_a + P_v + P_f + P_d,$$

where $P_l = P_{att} + P_{stk} + P_{mp} + P_{ttc}$,

$$P_{pc} = \frac{P_{pcu}}{\eta_{pcu}} = \frac{P_l + P_a + P_v + P_f + P_d}{\eta_{pcu}},$$

now $P_b = \dfrac{P_l + P'_a + P'_v + P'_f + P'_d}{\eta_{pc}\eta_{pcu}}$

and $P_{pt_1} = \dfrac{P_l + P_a + P_v + P_f + P_d}{\eta_{pc}\eta_{pcu}}$.

The total energy output from the batteries in watt-hours is

$$WH_{out} = \frac{H \bullet P_1 + WH_a + WH_v + WH_f + WH_d}{\eta_{pc}\eta_{pcu}}$$

where

H is the total number of hours per day of solar eclipse (1.2 hours for a geostationary orbit)

$$WH_k = \sum (H-h_j) \begin{bmatrix} \text{BLOCK} \\ \text{'ON' POWER} \end{bmatrix}_j + \sum (h_j) \begin{bmatrix} \text{BLOCK} \\ \text{STANDBY POWER} \end{bmatrix}_j$$

$k = a, v, f, d$

h_j is the number of hours during eclipse for standby of the j^{th} transmitter-receiver block

The total energy supplied to the batteries is

$$WH_{in} = \frac{WH_{out}}{\eta_b} = \frac{H\,P_1 + WH_a + WH_v + WH_f + WH_d}{\eta_b\eta_{pc}\eta_{pcu}}$$

and the required power is

$$P_{pt_2} = \frac{WH_{in}}{24-H} = \frac{H \bullet P_1 + WH_a + WH_v + WH_f + WH_d}{(24-H)\eta_b\eta_{pc}\eta_{pcu}}$$

The batteries are sized assuming a 50 percent depth-of-discharge requiring a capacity twice the output energy, WH_{out}.

Now the output of the power transfer is

$$P_{pt} = P_{pt_1} + P_{pt_2} = \frac{P_1 + P_a + P_v + P_f + P_d}{\eta_{pc}\eta_{pcu}} + \frac{H \bullet P_1 + WH_a + WH_v + WH_f + WH_d}{(24-H)\eta_b\eta_{pc}\eta_{pcu}}$$

and finally the required power source output is

$$P_{ps} = \frac{P_{pt}}{\eta_{pt}} = \frac{1}{\eta_{pt}\eta_{pc}\eta_{pcu}} \left[P_l + P_a + P_v + P_f + P_d + \frac{H \bullet P_l + WH_a + WH_v + WH_f + WH_d}{(24 - H)\eta_b} \right].$$

Because of the interdependence among the various satellite subsystems, an explicit solution of attitude control and stationkeeping parameters is precluded. The attitude control weight, volume, and power are a function of the solar array area and the stationkeeping characteristics are determined by the total of all of the remaining subsystem weights. Due to these relationships, an implicit solution is dictated as shown in Figure 2-12. The parametric values for each subsystem which is independent are determined and remain constant throughout the process. A nominal estimate is made for the parameters of the other subsystems — attitude control, stationkeeping, thermal control, and structure. The power subsystem is sized for these initial conditions. The structure is then sized as a function of the contained equipment; the thermal control requirements are determined for the required power dissipation. The attitude control subsystem parameters are computed for the solar array area and the stationkeeping subsystem is sized as a function of the weight of all other subsystems. The process is continued iteratively using the present state of values as the nominal until the difference in successive prime power requirements is sufficiently small.

2.8 REDUNDANCY MODEL

The program computes factors which scale the affected weight, volume and cost terms to reflect the redundant elements required for additional spacecraft life.

Let

ℓ_S = life of the satellite

ℓ_I = life of the equipment in question

ρ = a scale factor such that $0 \leq \rho \leq 1$

If $d = \dfrac{\ell_S - \ell_I}{\ell_I}$, then

the scaling factor S is given by $S = 1 + \rho \cdot d$.

The same scale factor is used for weight, volume, and cost terms.

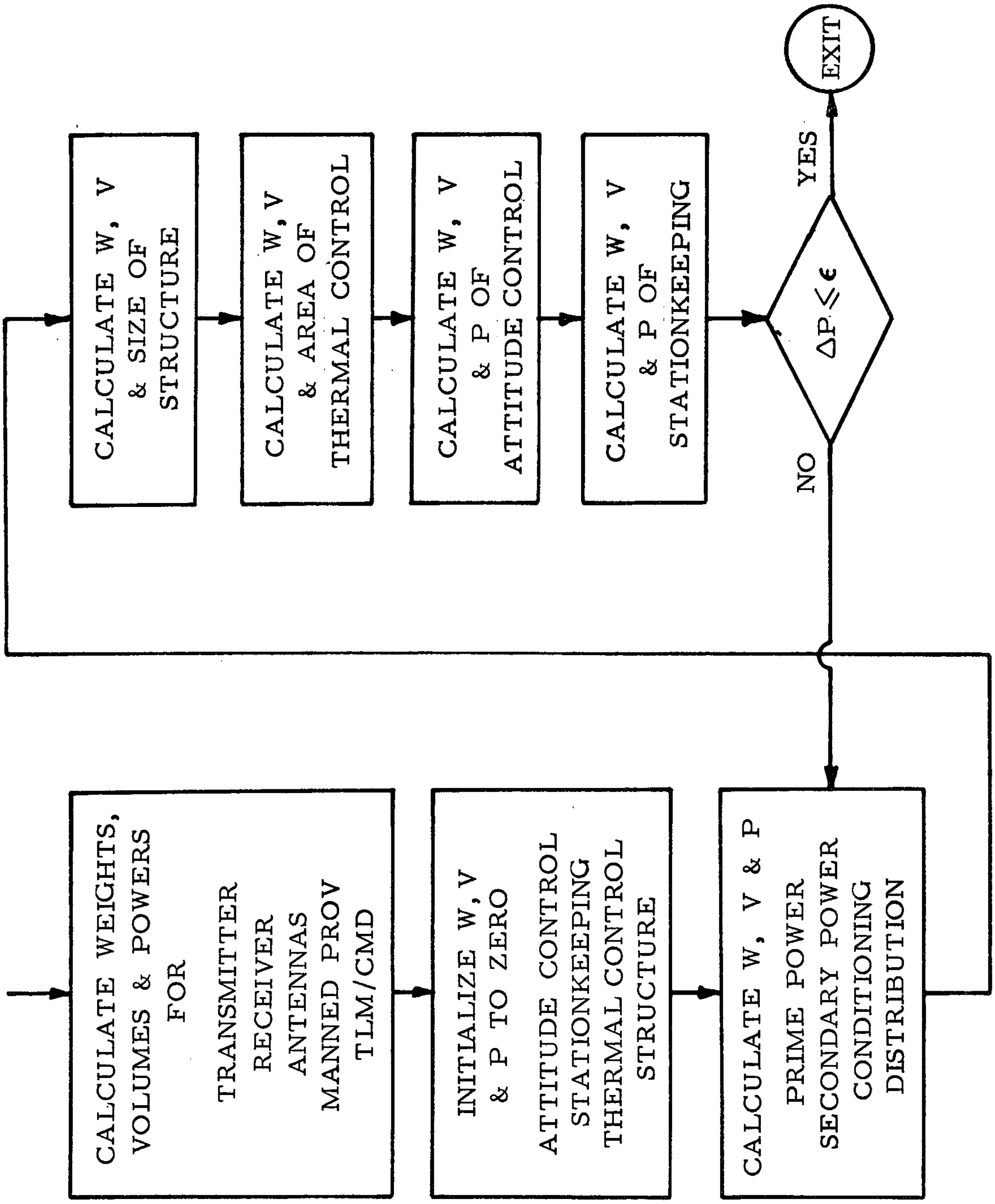


Figure 2-12. Iterative process for sizing satellite subsystems.

The list of equipment for which redundancy is provided includes the following:

a) downlink transmitter
b) spacecraft receiver
c) power transfer unit
d) power conditioning unit
e) power control unit
f) L/C filter

Each requires that the lifetime ℓ_I and the scaling factor ρ be input.

2.9 COMMUNICATION LINKS

The communication links are modeled using the relations shown in Figure 2-13 where

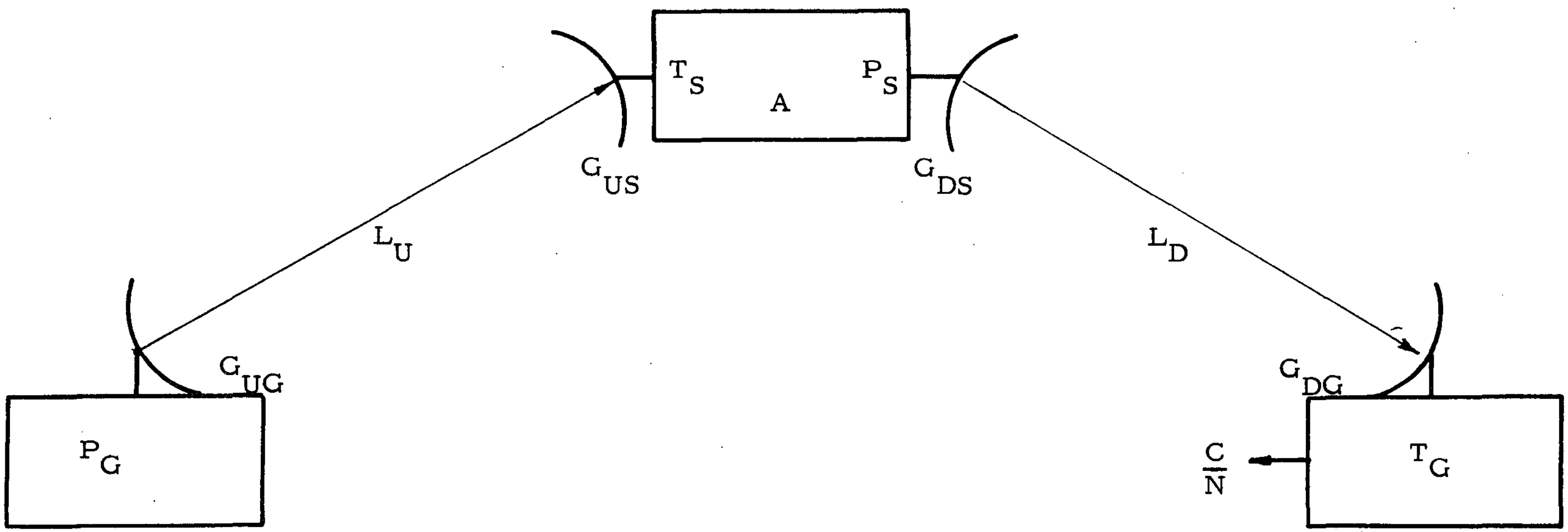
G	is	Antenna gain
P	is	Transmitter power
L	is	System attenuation
N	is	System noise
$\frac{C}{N}$	is	Carrier-to-noise ratio
A	is	Satellite transponder gain

Indicated subscripts are defined as follows:

U	indicates	uplink (at frequency f_U)
D		downlink (at frequency f_D)
G		ground based
S	indicates	Satellite
1		Station 1
2		Station 2

The receiver carrier-to-noise ratio of the signal transmitted by Station 1, transponded by the satellite, and received by Station 2 for a constant gain transponder is

$$\left.\frac{C}{N}\right|_2 = \frac{P_{G_1} G_{UG_1} L_U G_{US} A G_{DS} L_D G_{DG_2}}{N_{G_2} + N_{IM} + N_S A G_{DS} L_D G_{DG_2}}$$



$$\frac{C}{N} = \frac{P_G \cdot G_{UG} \cdot L_U \cdot G_{US} \cdot A \cdot G_{DS} \cdot L_D \cdot G_{DG}}{N_G + N_{IM} + A \cdot G_{DS} \cdot L_D \cdot G_{DG} \cdot N_S}$$

$$\frac{C}{N} = \frac{\left(P_S - AN_S\right) \cdot G_{DS} \cdot L_D \cdot G_{DG}}{N_G + N_{IM} + A \cdot G_{DS} \cdot L_D \cdot G_{DG} \cdot N_S}$$

Figure 2-13. Communications link analysis.

where N_{IM} is the intermodulation noise due to multicarrier operation through one transponder.

For the constant power transponder, the equation relating satellite transmitter power and carrier-to-noise ratio is

$$\left.\frac{C}{N}\right]_2 = \frac{(P_S - A\ N_S)\ G_{DS}\ L_D\ G_{DG_2}}{N_{G_2} + N_{IM} + N_S\ A\ G_{DS}\ L_D\ G_{DG_2}}$$

In both equations, the total noise is composed of three terms: receiving system noise, intermodulation noise, and noise on the downlink due to the uplink.

For the reverse link — station 2 to station 1 — the numerical subscripts are reversed.

2.10. SELECTION OF DEPENDENT AND INDEPENDENT DESIGN PARAMETER VECTORS

In this application, the choice of parameters for the dependent and independent vector varies with the case under consideration. Essentially, there are nine cases which the program will consider. The distinct cases are determined by the choice of transmit and receive capability of the Class I and/or Class II facilities and whether or not any direct receiving facilities are to be used. Figure 2-14 depicts the nine options which can be considered. Modifications to increase this number can be done with minimum effort.

The choice for the components of $\overline{Y}$, the vector of dependent parameters,is given as:

- y(1) — total satellite weight (lb)
- y(2) — total satellite volume (cu ft)
- y(3) — volume of the satellite equipment module (cu ft)
- y(4) — satellite prime power supply (watts)
- y(5), y(6),...y(28) — spacecraft transmitter power, power out/channel (watts)
- y(29), y(30),...y(52) — Class I transmitter power, power out/channel (watts)
- y(53), y(54),...y(76) — Class II transmitter power, power out/channel (watts)
- y(77) — direct ground antenna diameter or ground antenna diameter for selected dependent facility (ft)
- y(78) — direct ground antenna diameter (ft)

For the components of the independent design parameter vector, the choice is:

- x(1) — Class I or Class II ground facility antenna diameter (ft)

OPTION NO.	CLASS 1 STATION	CLASS 2 STATION	DIRECT STATION
1	T	—	R
2	T	R	—
3	T	R	R
4	T/R	—	—
5	T/R	—	R
6	T/R	R	—
7	T/R	R	R
8	T/R	T/R	—
9	T/R	T/R	R

Figure 2-14. Synthesis program ground system options.

x(2) — Class I, Class II, or direct ground antenna diameter (ft) or Class I receiver noise figure

x(3) — Class I, Class II, or direct receiver noise figure

x(4) — Class II or direct receiver noise figure

For the nine cases, the vectors are illustrated in Figures 2-15 and 2-16. The notation used in the charts is given by the following:

W_t = total satellite weight

V_t = total satellite volume

Vem = volume of satellite equipment module

P_{ps} = prime power supply (satellite)

Ptr_s = transmitter power (satellite)

Pg_1 = transmitter power (Class I)

Pg_2 = transmitter power (Class II)

D_1 = antenna diameter (Class I)

D_2 = antenna diameter (Class II)

D_3 = antenna diameter (direct)

Nf_1 = receiver noise figure (Class I)

Nf_2 = receiver noise figure (Class II)

Nf_3 = receiver noise figure (direct)

In cases six through nine the choice of the independent antenna diameter is made on the basis of which class requires the largest value for C/N. The remaining antenna diameter reverts to being a dependent parameter.

2.11 SOLUTION APPROACH

As previously mentioned the link equations are based on the required $\frac{C}{N}$ and this, in turn, is used to size the spacecraft. The key equations used in the power model are listed below. A more detailed discussion is found in Volume II which elaborates on the link model used in the program.

$$Ptr_{ij} = \frac{\left(\frac{C}{N}\right)_{ik} (\rho_{im} + \rho_u + 1) (N_g)_{ikj}}{(G_d)_k \ (G_{ds})_j \ (T_{\ell d})_{kj}}$$

CASE OPTION	y(1)	y(2)	y(3)	y(4)	y(5) - y(28)	y(29) -y(52)	y(53)- y(76)	y(77)	y(78)
1	W_t	V_t	Vem	P_{ps}	Ptr_s	---	---	---	---
2	W_t	V_t	Vem	P_{ps}	Ptr_s	---	---	---	---
3	W_t	V_t	Vem	P_{ps}	Ptr_s	---	---	D_3	---
4	W_t	V_t	Vem	P_{ps}	Ptr_s	Pg_1	---	---	---
5	W_t	V_t	Vem	P_{ps}	Ptr_s	Pg_1	---	D_3	---
6	W_t	V_t	Vem	P_{ps}	Ptr_s	Pg_1	---	D_1 or D_2	---
7	W_t	V_t	Vem	P_{ps}	Ptr_s	Pg_1	---	D_1 or D_2	D_3
8	W_t	V_t	Vem	P_{ps}	Ptr_s	Pg_1	Pg_2	D_1 or D_2	---
9	W_t	V_t	Vem	P_{ps}	Ptr_s	Pg_1	Pg_2	D_1 of D_2	D_3

Figure 2-15. Choice of parameters for dependent vector, $\overline{Y}$.

CASE OPTION	x(1)	x(2)	x(3)	x(4)
1	D_1	D_3	Nf_3	---
2	D_1	D_2	Nf_2	---
3	D_1	D_2	Nf_2	Nf_3
4	D_1	Nf_1	---	---
5	D_1	Nf_1	Nf_3	---
6	D_1 or D_2	Nf_1	Nf_2	---
7	D_1 or D_2	Nf_1	Nf_2	Nf_3
8	D_1 or D_2	Nf_1	Nf_2	---
9	D_1 or D_2	Nf_1	Nf_2	Nf_3

Figure 2-16. Choice of parameters for independent vector, $\overline{X}$.

$$Pg_{ijn} = \frac{\left(\frac{C}{N}\right)_{ik} (N_s)_{kj} (\rho_{im} + \rho_u + 1)}{(G_u)_n \ (G_{us})_j \ (T_{\ell u})_{nj}}$$

$$Pg_{ijn} = \frac{\left(\frac{C}{N}\right)_{in} (N_s)_{ij} \left[R \ \rho_{im} + \rho_u + (N_g)_{inj}\right]}{(G_u)_n \ (G_{us})_j \ (T_{\ell u})_{nj} \ (R) \ (N_g)_{ikj}}$$

where $R = \frac{(G_d)_n \ (T_{\ell d})_{nj}}{(G_d)_k \ (T_{\ell d})_{kj}}$

and the subscripts indicated are described as follows:

i = data type = 1, 2, 3, 4

j = beam number = 1, 2, 3,.....,6

k = fixed, representing independent class = 1 or 2

n = fixed, representing dependent class = 1 or 2

ρ_{im} = ratio of intermodulation noise/system noise

ρ_u = ratio of satellite noise/receiver noise

N_g = total noise at the ground receiver

G_d = ground antenna downlink gain for class k

G_{ds} = spacecraft antenna downlink gain

$T_{\ell d}$ = total loss down

N_s = total noise at the spacecraft

G_u = ground antenna uplink gain

G_{us} = spacecraft antenna uplink gain

$T_{\ell u}$ = total loss up

Total noise on the ground, N_g, is a function of the effective temperature. The effective temperature at each of the ground receivers is a function of the relative antenna discriminations due to sky, environment, and earth. These discriminations in turn are determined by the downlink gain at each of the receivers. The gain is computed directly as a function of diameter and frequency, except when the diameter is unknown and is given as one of the dependent parameters. In this case, an iteration scheme is used since the equations are of an implicit nature. The iteration scheme is initiated using the value of the gain for the independent class of stations.

The steps describing the approach for each of the case options are given here.

CASE OPTION I

$\overline{X}$ = (D_1, D_3, Nf_3)

1. compute satellite antenna characteristics (from frequency and area of coverage),

2a. compute Class I uplink gain, G_{u1},

2b. compute direct antenna downlink gain, G_{d3},

3. compute antenna discrimination for Class I and direct,

4. compute Class I uplink transmitter power, Pg_1 and satellite transmitter power, Ptr,

5. cost ground facility,

6. size spacecraft and compute associated parameters (weight, volume, power, and cost),

7. cost launch vehicle,

8. compute total cost.

CASE OPTION II

$\overline{X}$ = (D_1, D_2, Nf_2)

1. I - 1,

2a. I - 2a,

2b. compute Class II antenna downlink gain, G_{d2},

3. compute antenna discrimination for Class I and Class II,

4. I - 4,

5. I - 5 to I - 8.

CASE OPTION III

$\overline{X}$ = (D_1, D_2, Nf_2, Nf_3)

1. II - 1 to II - 4,

2. iterate for direct antenna diameter and gain,

3. compute direct antenna relative discriminations,

4. I - 5 to I - 8.

CASE OPTION IV

$\overline{X}$ = (D_1, Nf_1)

1. I - 1 and I - 2a,

2. compute Class I antenna downlink gain, G_{d1},

3. compute Class I antenna discrimination,

4. I - 4,

5. I - 5 to I - 8.

CASE OPTION V

$\overline{X}$ = (D_1, Nf_1, Nf_3)

1. I - 1,

2. compute Class I antenna downlink gain, G_{d1},

3. compute Class I antenna discriminations,

4. compute satellite transmitter power to be used in iteration scheme, Ptr (I, J) where I = JCLG and J = IBMG,

5. iterate for direct antenna diameter, D_3,

6. I - 2a,

7. compute direct antenna gain, G_{d3},

8. compute antenna discrimination for the direct antenna,

9. I - 4 to I - 8.

CASE OPTION VI

$\overline{X}$ = (D_j, Nf_1, Nf_2) where j = 1 or 2

1. I - 1,

2. determine independent antenna diameter, G_{dI}, and dependent antenna diameter, G_{dD},

3. compute downlink antenna gain for the independent antenna,

4. compute antenna discriminations for the independent antenna,

5. V - 4,
6. iterate for dependent antenna diameter,
7. I - 2a,
8. compute downlink gain for the dependent antenna,
9. compute the antenna discriminations for the dependent antenna,
10. I - 4 to I - 8.

CASE OPTION VII

$\overline{X} = (D_j, Nf_1, Nf_2, Nf_3)$ where j = 1 or 2

1. VI - 1 to VI - 9,
2. I - 4,
3. III - 2 to III - 4.

CASE OPTION VIII

$\overline{X} = (D_j, Nf_1, Nf_2)$ where j = 1 or 2

1. VI - 1 to VI - 9,
2. compute Class II uplink antenna gain, G_{u2},
3. I - 4,
4. compute Class II uplink transmitter power, Pg_2,
5. I - 5 to I - 8.

CASE OPTION IX

$\overline{X} = (D_j, Nf_1, Nf_2, Nf_3)$ where j = 1 or 2

1. VIII - 1 to VIII - 5,
2. III - 2 to III - 4.

2.12 OUTPUT

The ITS program provides two forms of output, one a brief summary printed at each iteration, and the second, a comprehensive printout at the conclusion of each case.

A sample of the first type is illustrated in Figure 2-17. This summary is provided for each iteration and provides the program user with indication of the nature of the system at any particular design point during the convergence process and the rate of convergence. The output provides the iteration number, the values of the key dependent parameters, the values of the independent design parameters, the computed perturbation, and the gradient vector. It also provides the number of boundary violations (NBV), the index of the one which violates its constraint by the largest degree (KBV), the number of successive iterations for which the convergence criteria is met (ICV), the number of components of X meeting the convergence criteria (JCV), the computed step size vector for the next iteration, and total system cost.

The variables listed are defined as follows:

WSAT	—	total satellite weight (lb)
VSAT	—	total satellite volumes (cu ft)
VEM	—	volume of the spacecraft equipment module (cu ft)
PPS	—	prime power supply (watts)
D(1) or D(2)	—	dependent Class I or Class II ground antenna diameter.
PG1	—	4 × 6 array of transmitter power out at Class I facilities (watts)
PG2	—	4 × 6 array of transmitter power out at Class II facilities (watts)
PTR	—	4 × 6 array of transmitter power out at the spacecraft (watts)

D(3), the direct receiving system antenna diameter is also provided when used.

The formal output at the conclusion of the run is intended to be a comprehensive easy-to-read listing of all pertinent parametric values.

Other than the output and computed values relevant to the user requirements and beam characteristics described in the previous sections, the output routine provides a systematic breakdown of other elements — primarily cost, weight and volume.

```
ITER= 24        PG1=     0.0        0.0       0.0       0.0       0.0       0.0
WSAT=  1332.4            0.0        0.0       0.0       0.0       0.0       0.0
VSAT=   110.9         1387.2        0.0       0.0       0.0       0.0       0.0
VEM =    66.1           12.4        0.0       0.0       0.0       0.0       0.0
PPS =  2425.9   PG2=     0.0        0.0       0.0       0.0       0.0       0.0
D(2)= 42.3686            0.0        0.0       0.0       0.0       0.0       0.0
                       928.2        0.0       0.0       0.0       0.0       0.0
                         1.9        0.0       0.0       0.0       0.0       0.0


PTR=      0.0        0.0        0.0        0.0        0.0        0.0
          0.0        0.0        0.0        0.0        0.0        0.0
        308.2        0.0        0.0        0.0        0.0        0.0
          5.9        0.0        0.0        0.0        0.0        0.0
X=  20.8755 DX= -0.09465 G=    0.0738 S= 0.5000  ICV=0  JCV=1
     8.6059       0.00112     -0.2238    0.0020  NBVIOL =  0
    10.1852      -0.09958      0.3106    0.1250  TOTAL COST=
     0.0          0.0          0.0       1.0000     345.7633
```

Figure 2-17. Iterative output summary.

A total system cost summary is provided on an annual cost basis for each of the major subsystems: the Class I, Class II, and direct ground systems, the satellite, the launch vehicle, and the telemetry and command.

A data service summary is provided for each of the four data categories on a per beam basis. This provides such information as base bandwidth, modulation, modulation index and total of bandwidth. (Figure 2-18)

The ground receiver characteristics are listed for each class of stations and provide a breakdown for each beam requiring that particular class. The information provides the number of channels transmitted and received, EIRP, G/T, S/N, and the total number of facilities for that beam.

The satellite antenna and transponder characteristics are given for each beam. These include the number of channels transmitted and received, G/T, and EIRP. The transponder characteristics list the antenna dimension and gains, beam center, beamwidth, and pattern axes for the uplink and downlink. (Figure 2-19)

A summary of the loss and noise terms are provided for the uplink and downlink beams. The noise terms include sky, earth, and environment, and receiver noise temperatures. The losses provided include free-space, atmospheric, rain, location, polarization, circuit, and pointing losses for the receiver and transmitter. On the downlink those applicable are given for each class of station. (Figure 2-20)

Finally a comprehensive summary is provided for each of the major subsystems: ground, spacecraft, and launch vehicle.

The ground facility summary is provided for each class of station and for each beam. The cost breakdown is given for each cost item comprising the ground system: facility, terminal equipment, transmitters, antenna and multiplexer, receiver, standby power, test equipment, personnel, and design, integration and management. The acquisition, installation, annual operations and maintenance, and total cost are listed for each. Also shown are the number of channels per data category, the required transmitter power, the antenna size and gain, and receiver noise figure. The total cost/facility is shown together with the total number of facilities for that particular beam. (Figures 2-21 and 2-22)

The satellite summary provides the acquisition cost, R/D cost (prorated), total cost, weight, and volume of the various spacecraft subsystems: prime power, secondary power, power conditioning, power distribution, antenna, transmitter, multiplexer, receiver, structure, thermal control, attitude control, stationkeeping, and telemetry/command. Descriptive parameters such as transmitter power and receiver noise figures are provided where pertinent. Also included is the cost

```
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                                                                                    PAGE    1

                                              USER REQUIREMENTS

                          SATELLITE LONG =-100.0 DEG        UPLINK FREQUENCY   = 12.00 GHZ
                          SATELLITE LIFE =  10.0 YEARS      DOWNLINK FREQUENCY = 12.20 GHZ
                          TOTAL SYS LIFE =  10.0 YEARS      NUMBER OF BEAMS    =    4


USER    X- - - - - - - -U S E R   D E S C R I P T I O N- - - - - - - - -X    RCVR     X----NUMBER OF STATIONS----X
 NO                                                                          ENVIR    CLASS 1   CLASS 2     DIRECT

03      EDUCATIONAL/INSTRUCTIONAL TELEVISION DISTRIBUTION (4 BEAMS)          URBAN        51     30200          0


USER    X- - - - -S Y S T E M   C O S T S    (M I L L I O N S / Y E A R)- - - - - - - - - - -X
 NO        TOTAL      CLASS 1      CLASS 2        DIRECT      SATELLITE  LAUNCH VEH     TLM/CMD

03       3684.468        7.019     3647.721         0.000         8.179     21.320        .228


USER    X- - - - - - - - - - - - - - - - - - - -V I D E O    D A T A- - - - - - - - - - - - - - - - - - -X
NO      SERVICE     BASE-    VEST-    NO AUDIO      MODULATION        MOD INDEX        RF BANDWIDTH
          TYPE      BAND     BAND     CHANNELS    UPLINK DNLINK    UPLINK DNLINK    UPLINK DNLINK
                    (MHZ)    (MHZ)     /VIDEO                                        (MHZ)   (MHZ)

03       COLOR      4.200    0.000       1          FM      FM       2.88    2.88     32.63   32.63
```

Figure 2-18. Final output — user requirements/major subsystems costs.

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BEAM NO	NO OF FAC	XMTD AUDIO	XMTD VIDEO	XMTD FAX	XMTD DIGIT	EIRP (DBW) AUDIO	EIRP VIDEO	EIRP FAX	EIRP DIGIT	RCVD AUDIO	RCVD VIDEO	RCVD FAX	RCVD DIGIT	G/T (DB/K)	S/N (DB) AUDIO	S/N VIDEO	S/N FAX	S/N DIGIT
CLASS 1 STATION CHARACTERISTICS																		
1	1	0	4	0	0	0.0	68.8	0.0	0.0	0	2	0	0	17.4	0.0	54.0	0.0	0.0
2	1	0	4	0	0	0.0	68.6	0.0	0.0	0	2	0	0	17.4	0.0	54.0	0.0	0.0
3	24	0	2	0	0	0.0	68.5	0.0	0.0	0	6	0	0	17.4	0.0	54.0	0.0	0.0
4	25	0	2	0	0	0.0	68.7	0.0	0.0	0	6	0	0	17.4	0.0	54.0	0.0	0.0
CLASS 2 STATION CHARACTERISTICS																		
1	100	0	0	0	0	0.0	0.0	0.0	0.0	0	2	0	0	10.6	0.0	44.5	0.0	0.0
2	100	0	0	0	0	0.0	0.0	0.0	0.0	0	2	0	0	10.6	0.0	44.5	0.0	0.0
3	15000	0	0	0	0	0.0	0.0	0.0	0.0	0	6	0	0	10.6	0.0	44.5	0.0	0.0
4	15000	0	0	0	0	0.0	0.0	0.0	0.0	0	6	0	0	10.6	0.0	44.5	0.0	0.0

SATELLITE TRANSPONDER CHARACTERISTICS

BEAM NO	NO OF CHANS RCVD AUDIO	RCVD VIDEO	RCVD FAX	RCVD DIGIT	G/T (DB/K)	NO OF CHANS XMTD AUDIO	XMTD VIDEO	XMTD FAX	XMTD DIGIT	EIRP (DBW) AUDIO	EIRP VIDEO	EIRP FAX	EIRP DIGIT
1	0	10	0	0	8.24	0	8	0	0	0.0	59.9	0.0	0.0
2	0	6	0	0	8.24	0	8	0	0	0.0	59.7	0.0	0.0
3	0	6	0	0	8.24	0	8	0	0	0.0	59.6	0.0	0.0
4	0	10	0	0	8.24	0	8	0	0	0.0	59.8	0.0	0.0

SATELLITE ANTENNA CHARACTERISTICS

BEAM NO	ANTENNA DIMENSIONS (FT)	(FT)	BEAM CENTER LAT (DEG)	LONG (DEG)	UPLINK GAIN (DB)	UPLINK BEAMWIDTHS (DEG)	(DEG)	UPLINK PATTERN AXES (MI)	(MI)	DOWNLINK GAIN (DB)	DOWNLINK BEAMWIDTHS (DEG)	(DEG)	DOWNLINK PATTERN AXES (MI)	(MI)
1	1.9	2.8	35.0	-78.0	36.3	3.05	2.03	1941	736	36.4	3.00	2.00	1904	724
2	1.9	2.8	38.0	-92.0	36.3	3.05	2.03	1838	728	36.4	3.00	2.00	1805	716
3	1.9	2.8	38.0	-104.0	36.3	3.05	2.03	1812	726	36.4	3.00	2.00	1779	714
4	1.9	2.8	35.0	-120.0	36.3	3.05	2.03	1889	732	36.4	3.00	2.00	1854	720

Figure 2-19. Final output — ground receivers, satellite transponder, and satellite antenna characteristics.

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BEAM NO	DOWNLINK NOISES (DEG K) SKY	ENVIR	EARTH	INTERMODULATION NOISE AUDIO	VIDEO	FAX	DIGIT	UPLINK CONTRIBUTION AUDIO	VIDEO	FAX	DIGIT	CLASS 1 RCVR	RCVR CKT	CLASS 2 RCVR	RCVR CKT	DIRECT RCVR	RCVR CKT	UPLINK NOISES EARTH	RCVR	RCVR CKT
1	83.8	.8	290.0	0.0	0.0	0.0	0.0	0.0	349.7	0.0	0.0	3377.2	59.6	*93.9	59.6	0.0	107.0	290.0	290.0	59.6
2	78.1	.8	290.0	0.0	0.0	0.0	0.0	0.0	349.3	0.0	0.0	3377.2	59.6	*93.9	59.6	0.0	107.0	290.0	290.0	59.6
3	76.7	.8	290.0	0.0	0.0	0.0	0.0	0.0	349.2	0.0	0.0	3377.2	59.6	*93.9	59.6	0.0	107.0	290.0	290.0	59.6
4	80.9	.8	290.0	0.0	0.0	0.0	0.0	0.0	349.5	0.0	0.0	3377.2	59.6	*93.9	59.6	0.0	107.0	290.0	290.0	59.6

BEAM NO	UPLINK LOSSES (DB) FREE-SPACE	ATMOSPHRIC	RAIN	LOCATION	SAT RCVR CKT	SAT RCVR POINT	CLASS 1 STATION XMIT CKT	XMIT POINT	POLARZATION	ELEV (DEG)	CLASS 2 STATION XMIT CKT	XMIT POINT	POLARZATION	ELEV (DEG)
1	-205.8	-1.5	-.5	-2.0	-1.0	-.1	-3.0	-.1	0.0	29.1	-3.0	-.1	-3.0	29.1
2	-205.7	-1.4	-.5	-2.0	-1.0	-.1	-3.0	-.1	0.0	32.0	-3.0	-.1	-3.0	32.0
3	-205.7	-1.4	-.5	-2.0	-1.0	-.1	-3.0	-.1	0.0	32.8	-3.0	-.1	-3.0	32.8
4	-205.8	-1.5	-.5	-2.0	-1.0	-.1	-3.0	-.1	0.0	30.5	-3.0	-.1	-3.0	30.5

BEAM NO	DOWNLINK LOSSES (DB) FREE-SPACE	ATMOSPHRIC	RAIN	LOCATION	SAT XMTR CKT	SAT XMTR POINT	CLASS 1 STATION RCVR CKT	RCVR POINT	POLARZATION	ELEV (DEG)	CLASS 2 STATION RCVR CKT	RCVR POINT	POLARZATION	ELEV (DEG)	DIRECT RECEIVER RCVR CKT	RCVR POINT	POLARZATION	ELEV (DEG)
1	-205.9	-1.6	-.5	-2.1	-2.1	-.1	-1.0	-.1	0.0	29.1	-1.0	-.1	-3.0	29.1	-2.0	-2.0	-3.0	29.1
2	-205.9	-1.5	-.5	-2.1	-2.1	-.1	-1.0	-.1	0.0	32.0	-1.0	-.1	-3.0	32.0	-2.0	-2.0	-3.0	32.0
3	-205.9	-1.4	-.5	-2.1	-2.1	-.1	-1.0	-.1	0.0	32.8	-1.0	-.1	-3.0	32.8	-2.0	-2.0	-3.0	32.8
4	-205.9	-1.5	-.5	-2.1	-2.1	-.1	-1.0	-.1	0.0	30.5	-1.0	-.1	-3.0	30.5	-2.0	-2.0	-3.0	30.5

Figure 2-20. Final output — loss and noise summary.

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GROUND STATIONS - BEAM 1 (THOUSANDS)

CLASS 1 FACILITIES	ACQUISITION	INSTALL	OPER/YEAR	MAINT/YEAR	TOTAL	
FACILITY	110.00	-	-	2.20	132.00	
TERMINAL EQUIP-VIDEO	120.00	24.00	18.00	12.00	444.00	NO. CHANS = 6
TRANSMITTERS-VIDEO	111.64	22.33	1.27	11.16	258.30	POWER = .080 KW
ANTENNA + MUX	30.64	0.00	-	3.06	61.28	DIA = 15.63,
RECEIVERS	4.26	.64	.21	.43	11.28	NOISE FIG =11.02
STANDBY POWER	77.63	1.55	-	3.88	117.99	
TEST EQUIPMENT	50.00	-	-	-	50.00	
PERSONNEL	-	-	60.00	-	600.00	
DESIGN, INTEG + MGMT	-	39.98	-	-	39.98	
TOTAL/FACILITY	504.16	88.50	79.48	32.73	1714.83	NO FAC/BEAM = 1

CLASS 2 FACILITIES	ACQUISITION	INSTALL	OPER/YEAR	MAINT/YEAR	TOTAL	
FACILITY	50.00	-	-	1.00	60.00	
TERMINAL EQUIP-VIDEO	120.00	24.00	18.00	12.00	444.00	NO. CHANS = 2
ANTENNA + MUX	3.30	.20	-	.33	6.79	DIA = 9.95,
RECEIVERS	.83	.13	.04	.08	2.21	NOISE FIG =14.00
STANDBY POWER	41.89	.84	-	2.09	63.68	
TEST EQUIPMENT	25.00	-	-	-	25.00	
PERSONNEL	-	-	30.00	-	300.00	
DESIGN, INTEG + MGMT	-	18.62	-	-	18.62	
TOTAL/FACILITY	241.02	43.78	48.04	15.51	920.30	NO FAC/BEAM = 100

Figure 2-21. Final output — ground facility cost summary (1)

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GROUND STATIONS - BEAM 4 (THOUSANDS)

CLASS 1 FACILITIES	ACQUISITION	INSTALL	OPER/YEAR	MAINT/YEAR	TOTAL	
FACILITY	70.00	-	-	1.40	84.00	
TERMINAL EQUIP-VIDEO	120.00	24.00	18.00	12.00	444.00	NO. CHANS = 8
TRANSMITTERS-VIDEO	55.50	11.10	1.27	5.55	134.79	POWER = .079 KW
ANTENNA + MUX	26.64	0.00	-	2.66	53.28	DIA = 15.63,
RECEIVERS	12.77	1.91	.64	1.28	33.83	NOISE FIG =11.02
STANDBY POWER	70.37	1.41	-	3.52	106.96	
TEST EQUIPMENT	50.00	-	-	-	50.00	
PERSONNEL	-	-	42.43	-	424.26	
DESIGN, INTEG + MGMT	-	32.24	-	-	32.24	
TOTAL/FACILITY	405.28	70.66	62.33	26.41	1363.36	NO FAC/BEAM = 25

CLASS 2 FACILITIES	ACQUISITION	INSTALL	OPER/YEAR	MAINT/YEAR	TOTAL	
FACILITY	90.00	-	-	1.80	108.00	
TERMINAL EQUIP-VIDEO	120.00	24.00	18.00	12.00	444.00	NO. CHANS = 6
ANTENNA + MUX	3.30	.20	-	.33	6.79	DIA = 9.95,
RECEIVERS	2.50	.38	.13	.25	6.63	NOISE FIG =14.00
STANDBY POWER	53.20	1.06	-	2.66	80.87	
TEST EQUIPMENT	25.00	-	-	-	25.00	
PERSONNEL	-	-	51.96	-	519.62	
DESIGN, INTEG + MGMT	-	18.87	-	-	18.87	
TOTAL/FACILITY	294.00	44.51	70.09	17.04	1209.77	NO FAC/BEAM = 15000

Figure 2-22. Final output — ground facility cost summary (2)

breakdown for integration, assembly and checkout, design, integration, and management, center support and ground support equipment. The total/satellite is given for the cost, weight, and volume. (Figure 2-23)

The launch vehicle summary provides the acquisition, R/D (prorated), and total cost for the launch vehicle. Also shown is the weight and volume limits.

A further breakdown for each beam is listed for the satellite communication subsystem. The summary provides cost, power, efficiency, lifetime for the transmitter, multiplexer, receiver, and antenna and the number of multiple transmitter blocks employed in the satellite.

SATELLITE SUBSYSTEMS	COSTS (MILLIONS) ACQUISITION	R+D	TOTAL	WEIGHT (LBS.)	VOLUME (CU FT)	TYPE	DESCRIPTIVE PARAMETERS
POWER SUBSYSTEM							
PRIME POWER	8.15	3.18	11.33	4327.1	722.62	SOLAR	POWER = 29.424 KW
SECONDARY POWER	.16	.23	.39	5653.6	42.99	NI-CAD	CAPACITY = 63.087 KW-H
CONDITIONING	.36	.32	.68	2091.2	21.91		
DISTRIBUTION	.90	.45	1.35	698.8	48.33		
ANTENNA	.00	.04	.04	44.1	15.51		4 BEAMS
TRANSMITTER	7.26	.79	8.05	2797.4	109.32	TWT	32 TRANSMITTERS
MULTIPLEXER	.31	.62	.93	21.4	.71	WAVEGUID	
RECEIVERS	2.22	.46	2.68	700.0	12.50	LIN TRNS	NOISE FIG = 3.0 DB
STRUCTURE	.16	.55	.70	121.1	64.96		H = 3.9, D = 10.0 FT
THERMAL CONTROL	.19	1.44	1.62	229.6	45.92	HEATPIPE	PWR RAD = 22.620 KW
STATION KEEPING	.59	5.23	5.82	529.1	.95	ION PROP	
ATTITUDE CONTROL	.88	5.09	5.97	108.7	1.38	ION PROP	AM/L = 6412.6 SQ FT
TELEMETRY + COMMAND	.17	.85	1.02	70.0	2.00		
PROTOTYPE	-	14.41	14.41				1 PROTOTYPE(S)
INTEG, ASSY + CHECK	1.60	-	1.60				
DESIGN, INTEG + MGMT	-	9.63	9.63				
CENTER SUPPORT	3.44	1.44	4.88				
GRD SUPPORT EQUIP	-	10.67	10.67				
	--------	--------	--------	--------	--------		
TOTAL/SATELLITE	26.37	55.42	81.79	17392.2	1089.12		
SYSTEM TOTAL	26.37	55.42	81.79				1 SATELLITE(S)

LAUNCH VEHICLE	COSTS (MILLIONS) ACQUISITION	R+D	TOTAL	WEIGHT LIMIT	VOLUME LIMIT		
TOTAL/LAUNCH VEH	188.20	25.00	213.20	52500.0	6000.00	SATURN V	1 SATS/LAUNCH
SYSTEM TOTAL	188.20	25.00	213.20				1 LAUNCH VEHICLES

SATELLITE COMMUNICATIONS SUBSYSTEMS

BEAM NO. 1	UNIT ACQ	TOTAL ACQ	TOTAL WEIGHT	TOTAL VOLUME	POWER (WATTS)	EFFIC-IENCY	UNIT LIFE	MOD	NO.XMTR BLOCKS	NO XMTRS /BLOCK	
TRANSMITTER- TWT -VIDEO	.05	1.83	708.9	27.34	352	53.7	2	FM	8	5	
MULTIPLEX-WAVEGUID		.08	5.4	.18							LOSS=-1.1 DB
RECEIVER-LIN TRNS		.67	210.0	3.75	30		2				NF = 3.0 DB
ANTENNA- RIGID		.00	11.0	3.88							1.9 X 2.8 FT

Figure 2-23. Final output — satellite subsystems and launch vehicle summary.

APPENDIX A

DERIVATION OF STEEPEST DESCENT ITERATIVE ALGORITHM

Let X represent a vector of n independent system design parameters, y(X) a vector of m constrained system parameters, and C(X) the total system cost. It is desired to determine the minimum value of C subject to the constraints imposed on y. This solution is to be obtained by iteratively perturbing a nominal design parameter vector X_i until no futher reduction in C is possible and all constraints are satisfied. At each iteration only those constraints which have been violated need be considered.

Now let y be a k-vector whose elements are those parameters whose boundaries have been violated (a subset of the original y vector). For these parameters the constraint

$$y(X) - y_{BOUND} = 0 \tag{1}$$

will be imposed. At a given iteration

$$Y_i = y(X_i) - y_{BOUND} \neq 0 \tag{2}$$

Let g and Φ represent the cost and constraint gradients, respectively. That is,

$$g = \frac{dC}{dX}(X_i) \text{ and } \Phi = \frac{dy}{dX}(X_i) \tag{3}$$

To first order terms

$$\Delta C(\Delta X) = g^T \cdot \Delta X \tag{4}$$

and

$$\Delta Y = \Phi^T \cdot \Delta X \tag{5}$$

It is desired to determine the vector ΔX which minimizes

$$J = \Delta C(\Delta X) = g^T \cdot \Delta X \tag{6}$$

while reducing ΔY by some specified amount

$$\Delta Y = - K_y \cdot Y \tag{7}$$

The magnitude of the perturbation is constrained by

$$S^2 = \Delta X^T \cdot \Delta X \tag{8}$$

Applying Lagrange multiplier theory one defines J' to be

$$J' = g^T \cdot \Delta X + \lambda \cdot (\Delta X^T \cdot \Delta X - S^2) + \eta^T \cdot (\Phi^T \cdot \Delta X + K_y \cdot Y) \tag{9}$$

where λ is an arbitrary constant and η is an arbitrary k-vector. From Equations 7 and 8 it is clear that J and J' are equal, so one can proceed by minimizing J'. This minimum occurs where

$$\frac{dJ'}{d\Delta X} = g^T + 2\,\lambda \cdot \Delta X^T + \eta^T\,\Phi^T = 0 \tag{10}$$

Solving Equation (10) for ΔX gives

$$\Delta X = -\,\frac{1}{2\lambda} \cdot (g + \Phi \cdot \eta) \tag{11}$$

For convenience define

$$K_c = -\,\frac{1}{2\lambda} \text{ and } \gamma = -\,\frac{1}{2\lambda} \cdot \eta \tag{12}$$

Then

$$\Delta X = -\,K_c \cdot g - \Phi \cdot \gamma \tag{13}$$

Substituting Equation (13) into Equations (5) and (7) gives

$$\Delta Y = -\,K_c\,\Phi^T g - \Phi^T \Phi\,\gamma = -\,K_y \cdot Y \tag{14}$$

Solving for γ gives

$$\gamma = -\,K_c\,(\Phi^T\Phi)^{-1} \cdot \Phi^T \cdot g + K_y\,(\Phi^T\Phi)^{-1} \cdot Y \tag{15}$$

Substituting Equation (15) into Equation (13) gives

$$\Delta X = -\,K_c \left[\, I - \Phi\,(\Phi^T\Phi)^{-1}\,\Phi^T \,\right] \cdot g - K_y \cdot \Phi\,(\Phi^T\Phi)^{-1} \cdot Y \tag{16}$$

which is the perturbation equation given in Section 2.2.

The two terms of Equation (16) represent perturbations parallel and perpendicular to the constraint boundaries, respectively. This can be shown by taking the vector inner product (vector projection) of the first term and the constraint gradient

$$\Phi^T \cdot \left\{ - K_c \left[I - \Phi (\Phi^T \Phi)^{-1} \Phi^T \right] g \right\} = - K_c \left[\Phi^T - (\Phi^T \Phi) (\Phi^T \Phi)^{-1} \Phi^T \right] g$$

$$= - K_c \left[\Phi^T - \Phi^T \right] g = 0 \qquad (17)$$

The value of K_c can be determined by substituting Equation (16) into Equation (8) and reducing to

$$S^2 = K_y^2 \, Y^T (\Phi^T \Phi)^{-1} Y + K_c^2 \cdot H^T H \qquad (18)$$

where

$$H = \left[I - \Phi (\Phi^T \Phi)^{-1} \Phi^T \right] g \qquad (19)$$

Then

$$K_c = \sqrt{\frac{S^2 - K_y^2 \cdot Y^T (\Phi^T \Phi)^{-1} Y}{H^T H}} \qquad (20)$$

The step-size S is controlled to insure rapid convergence to the solution. When the nominal value of X is "far" from the solution successive perturbations will tend to be in the same direction. Under this condition it is desirable to increase S for the following iteration. When the nominal X is "close" to the solution such that a given perturbation overshoots the solution, successive perturbations will tend to be in opposite directions. Under this condition it is desirable to reduce S to allow the minimum cost solution to be determined to a finer resolution. The logic for implementing this step-size control is given in Section 2.2.

APPENDIX B

GENERAL PURPOSE SUBROUTINES

The ITS computer program requires the following general purpose system routines. Listings for each are provided. For the IBM 360 version, some may be replaced by the appropriate subroutines from the IBM library.

<u>General Purpose Routines</u>

1. Subroutine DSHIFT — to move an N by M matrix A into B
2. Subroutine DZERO — to clear an N by M array
3. Subroutine MTMPY — to form the product of two matrices
4. Subroutine MADD — to form the sum of two matrices

<u>Functions</u>

1. DVMAG — to compute the magnitude of a vector
2. VDOT — to form the vector dot product of two vectors

1. <u>Subroutine DSHIFT</u>

Purpose: to move an N by M matrix A into B

Usage: CALL DSHIFT (N, M, A, B)
where A and B are assumed to be matrices dimensioned N by M

2. <u>Subroutine DZERO</u>

Purpose: to clear an N by M array

Usage: CALL ZERO (A, N, M)
where A is the array to clear and N and M are the dimensions of A

3. <u>Subroutine MTMPY</u>

Purpose: to form the product of two matrices $C = A * B$

Usage: CALL MTMPY (A, B, C, N, M, L)

where A is an N by M matrix
B is an M by L matrix, and
C is the resultant N by L matrix

Note: A and B may be the same matrix, but C must be a separate matrix.

4. Subroutine MADD

Purpose: to form the sum of two matrices $R = F_1 A_1 + F_2 A_2$

Usage: CALL MADD (N, M, A_1, F_1, A_2, F_2, R)

where
A_1 and A_2 are N by M matrices,
F_1 and F_2 are scalar factors of A_1 and A_2, and
R is the resultant N by M matrix.

5. Function DVMAG

Purpose: to compute the magnitude of an N dimensional vector V

Usage: VM = VMAG (V, N)

where V is an N-dimensional vector and VM is the resultant magnitude

6. Function VDOT

Purpose: to compute the scalar product of two vectors A and B

$S = A \cdot B$

Usage: S = VDOT (A, B, N)

where A and B are N dimensional vectors and S is the resultant scalar product

The following library functions are referenced:

FUNCTION	DEFINITION
SIN (X)	Sine × (radians)
ASIN (X)	Arcsine × (radians)
COS (X)	Cosine × (radians)
ACOSD (X)	Arccosine × (degrees)
TAN (X)	Tangent × (radians)
ATAN (X)	Arctangent × (radians)
SQRT (X)	Square root of X
ALOG10 (X)	Log to the base 10 of X
EXP (X)	e to the X^{th} power

```
      SUBROUTINE DSHIFT(I,J,A,B)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION A(I,J),B(I,J)
      DO 1 K=1,I
      DO 1 L=1,J
    1 A(K,L) = B(K,L)
      RETURN
      END
```



```
      SUBROUTINE DZERO(A,I,J)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION A(1)
      K = I * J
      DO 1 L=1,K
    1 A(L) = 0.0
      RETURN
      END
```

```
      SUBROUTINE MTMPY(A,B,C,M,N,L)
C        SUBROUTINE TO FORM THE PRODUCT OF TWO MATRICES
C                 A IS AN M BY N MATRIX
C                 B IS AN N BY L MATRIX
C                 C IS THE RESULTANT M BY L MATRIX
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION A(M,N), B(N,L), C(M,L)
      DO 20 I=1,M
      DO 20 J=1,L
      C(I,J) = 0.0
      DO 20 K=1,N
   20 C(I,J) = C(I,J) + A(I,K)*B(K,J)
      RETURN
      END
```

```
      SUBROUTINE MADD(N,M,A1,F1,A2,F2,R)
C        SUBROUTINE TO ADD TWO N  BY  M MATRICES
C                 A1 AND A2 ARE N BY M MATRICES
C                 R IS THE RESULTANT MATRICES
C                 F1 AND F2 ARE SCALAR FACTORS OF A1 AND A2
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION A1(1), A2(1), R(1)
      M1 = M*N
      DO 100 I=1,M1
  100 R(I) = F1*A1(I) + F2*A2(I)
      RETURN
      END
```

```
      FUNCTION DVMAG(A,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION A(1)
      SUM = 0.
      DO 10 I=1,N
   10 SUM = SUM + A(I) * A(I)
      DVMAG = DSQRT(SUM)
      RETURN
      END
```

```
      FUNCTION VDOT(A,B,N)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION A(N), B(N)
      S = 0.
      DO 1 I=1,N
    1 S = S + A(I) * B(I)
      VDOT = S
      RETURN
      END
```


7.8

APPENDIX C

IBM 360 VERSION OVERLAY STRUCTURE

Since the core storage requirements increase significantly in converting the program from the CDC 6400 version to the IBM 360 version, it is recommended that the overlay feature be used. The increased storage requirement, which could amount to 30% or more, is due to the shortened word length (32 bits/word vs. 60 bits/word) and the need to revert to the use of double precision.

Because of the fact that the major computations are contained within the do-loop system, the number of prospective subroutines to share the same levels is restricted; the philosophy of the overlay feature being to retain in core those modules which are used consistently and flip in and out those which are used with less frequency.

The resident level should then consist of the subroutines which are used for each iteration. This excludes the following list:

Subroutine INPTX
AOC
CHANEL
DIAM
ATTEN
PARBDS
XBD

These essentially are initialization routines and hence need not be maintained in core during the executions of the steepest-descent iterative process. For the CDC 6400 version these represent approximately 13% of the allocated core.

Subroutines OUTPT1 and OUTPT2 are used only once per case and need not be resident. These routines comprise approximately 41% of the core.

The remaining ITS program subroutines and system subroutines make up the remainder; the driver routine requiring only 6% of the core requirement. Therefore to implement the overlay, three levels of routines may be considered:

Resident:

Driver routine (6%)

α level:

Initialization routines (13%)

INPTX
AOC
CHANEL
DIAM
ATTEN
PARBDS
XBD

β level:

System routine (38%)

EQUAT	PXTR	SPCRFT	RCVRS
OPTMUM	DISCR	ANTS	STNKP
BNDV	DGDEP	ATTCN	STRUC
CNVRGE	GRDFAC	MANPRV	TLMCMD
DIAGN	GDIRCT	MTPLXS	THRML
MAXBD	LNCHV	POWER	XMTR
	TOTCST		PLACE

γ level:

Output routine (41%)

OUTPT1, OUTPT2

Added to these are the required operating system routines.

To accomplish the overlay, only one level is considered — level α. Three separate packages are interchanged during execution.

α_1 — INPTX

α_2 — EQUAT, OPTMUM, BNDV, CNVRGE, MAXBD, PXTR, DISCR, DGDEP, POWER, RCVRS, STNKP, STRUC, TLMCMD, THRML, XMTR, PLACE, GRDFAC, GDIRCT, LNCHV, TOTCST, SPCRFT, ANTS, MANPRV, MTPLXS, ATTEN, VDOT, DVMAG

α_3 — OUTPT1, OUTPT2

All else is resident.